6 SOURCE ASSESSMENT – METHYLMERCURY

The Delta mercury TMDL program addresses the sources of two constituents, methyl and total mercury. The program focuses on methylmercury because, as described in Chapter 5, the Delta linkage analysis demonstrated a statistically significant, positive correlation between methylmercury levels in water and fish tissue. The program also addresses total mercury because: methylmercury production has been found to be a function of the total mercury content of sediment (Chapter 3); the mercury control program for the Delta must maintain compliance with the USEPA's CTR criterion for total recoverable mercury in freshwater sources; and the mercury control program for San Francisco Bay has assigned a total mercury load reduction of 110 kg/yr to the Central Valley (Johnson & Looker, 2004). Sources and losses of methylmercury are described in this chapter. Sources and losses of total mercury and suspended sediment are described in Chapter 7. All the mass load calculations are based on Equation 6.1:

Equation 6.1:

$$M_x = C_x * V$$

Where: M_x = Mass of constituent, X
C_x = Concentration of constituent, X, in mass per volume
V = Volume of water

Average annual methylmercury loads were estimated for water years (WY) 2000 to 2003, a relatively dry period that encompasses the available methyl and total mercury concentration data for the major Delta inputs and exports. Section 6.1 and Appendix E describe the water volumes upon which the loads are based. Sections 6.2 and 6.3 describe the methylmercury concentration data for all major sources and sinks and identify data gaps and uncertainties. Section 6.4 reviews the results and potential implications of the methylmercury mass balance. Mass balances are useful because the difference between the sum of known inputs and exports is a measure of the uncertainty of the measurements and of the importance of other unknown processes at work in the Delta.

6.1 Water Budget

Water inputs and losses were evaluated for the WY2000-2003 period, a relatively dry period that encompasses the available methylmercury concentration data for the major Delta inputs and exports (Section 6.2). In addition, the WY1984-2003 period was evaluated to illustrate the importance of wet years, particularly for total mercury and sediment loading from the Yolo Bypass (Chapter 7). This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. An assessment of a typical distribution of wet and dry water years is critical to the understanding of mercury and sediment sources because, as illustrated in the daily total mercury load graphs in Appendix J, the load for several high flow days may be equivalent to the annual load of the system during a dry year.

Water volume information for Delta inputs and exports was obtained from a variety of sources. USGS and DWR gages provided daily flows for the major tributaries to the Delta. The Dayflow model was used to estimate daily flow to San Francisco Bay, the Delta Mendota Canal (DMC), and the State Water Project (SWP). The Delta Island Consumptive Use Model was used to estimate Delta agricultural diversion and return flows. Average annual precipitation and land use acreages were used to estimate wet weather inputs from urban areas, atmospheric deposition, and tributaries with no flow gages. Project files were reviewed to determine average annual discharges from NPDES-permitted facilities in the Delta and annual average volumes removed by dredging projects. Appendix E provides a detailed description of the methods used to estimate annual average flow for the different water sources.

The WY2000-2003 water budget balances within about 2%, and the WY1984-2003 water budget balances to within about 1% (Table 6.1). This indicates that all major water inputs and exports have been identified. The Sacramento River, San Joaquin River and Yolo Bypass are the primary water sources, with the Sacramento River providing the majority of flow. The primary sinks are San Francisco Bay and the State and Federal pumps that transport water to the southern part of the State. The majority of water movement in the Delta is down the Sacramento River to San Francisco Bay and through a series of interconnecting channels to the State and Federal pumps. Most of the water in winter and spring flows to San Francisco Bay while in summer and fall the State and Federal pumps export a larger fraction south of the Delta (DWR, 1995).

6.2 Methylmercury Sources

The following were identified as sources of methylmercury to the Delta: tributary inflows from upstream watersheds, sediment flux, municipal wastewater, agricultural drainage, and urban runoff. Table 6.2 lists the average methylmercury concentrations and estimated average annual loads for each for WY2000-2003. The following sections illustrate the locations of the sources, describe the available methylmercury concentration data, and identify data gaps and uncertainties associated with the load estimates.

6.2.1 Tributary Inputs

Tributaries contribute more than 60% of Delta methylmercury inputs. Figure 6.1 illustrates the tributary watersheds that drain to the Delta. Several sampling efforts have taken place to characterize tributary inputs. Central Valley Water Board staff conducted monthly aqueous methylmercury sampling in the four major tributaries – Sacramento River, San Joaquin River, Mokelumne River, and Prospect Slough in the Yolo Bypass – from March 2000 to September 2001 (Foe, 2003). In addition, other programs conducted periodic aqueous methylmercury sampling on the Sacramento River between July 2000 and June 2003 (SRWP, 2004; CMP, 2004; Stephenson *et al.*, 2002). Monthly sampling by Central Valley Water Board staff resumed in April 2003. Of the three Sacramento River sampling locations included in the linkage analysis (Chapter 5) – Freeport, River Mile 44 and Greene's Landing – Freeport is the most upstream location and is used to characterize loads from the Sacramento River watershed[31] (Table 6.2).

[31] The Delta area that drains to the 13-mile reach of the Sacramento River between Freeport (near river mile 46) and the I Street Bridge (the northernmost legal Delta boundary, near river mile 59) is predominantly urban and is encompassed by the urban load estimate described in Section 6.2.5. No attempt was made to subtract this area from the Sacramento River watershed load estimate. Therefore, the Sacramento River load noted in Table 6.2 incorporates a small portion of the within-Delta urban runoff loading.

Table 6.1: Average Annual Water Volumes for Delta Inputs and Losses

Inputs & Exports	WY2000-2003		WY1984-2003	
	Water Volume (M acre-feet/yr)	% All Water	Water Volume (M acre-feet/yr)	% All Water
Tributary Sources (% of All Inputs)				
Sacramento River	15.1	78%	16.1	69%
Yolo Bypass	1	5.2%	2.7	11%
San Joaquin River	1.8	9.3%	3	13%
Mokelumne-Cosumnes River	0.48	2.5%	0.7	3.0%
Calaveras River	0.14	0.72%	0.15	0.64%
Morrison Creek	0.064	0.33%	0.067	0.29%
French Camp Slough	0.063	0.32%	0.066	0.28%
Ulatis Creek	0.030	0.15%	0.031	0.13%
Bear/Mosher Creeks	0.028	0.14%	0.029	0.12%
Marsh Creek (a)	0.006	0.03%	0.006	0.03%
Other Small Drainages to Delta (b)	0.094	0.48%	0.097	0.41%
Sum of Tributary Inputs	**18.8**	**96.9%**	**22.9**	**97.4%**
Within-Delta Sources (% of All Inputs)				
Wastewater (Municipal & Industrial) (a)	0.25	1.3%	0.25	1.1%
Atmospheric (Direct)	0.093	0.48%	0.097	0.41%
Atmospheric (Indirect)	0.15	0.77%	0.16	0.68%
Urban	0.064	0.33%	0.066	0.28%
Sum of Within-Delta Inputs	**0.56**	**2.9%**	**0.57**	**2.4%**
Exports (% of All Exports)				
Outflows to San Francisco Bay [X2]	12	63%	17	73%
State Water Project	3.2	17%	2.6	11%
Delta Mendota Canal	2.5	13%	2.4	10%
Agricultural Diversions (a)	0.99	5.2%	0.99	4.2%
Evaporation	0.30	1.6%	0.3	1.3%
Dredging (a)	0.00024	0.001%	0.00024	0.001%
Sum of Inputs	**19.4 M acre-feet**		**23.5 M acre-feet**	
Sum of Exports	**19.1 M acre-feet**		**23.3 M acre-feet**	
Input - Export	**0.3 M acre-feet**		**0.2 M acre-feet**	
Exports / Inputs	**98%**		**99%**	

(a) Only WY2001-2003 flow data were available for Marsh Creek. Wastewater volume is based on 2005 discharger information. Agricultural diversion volume is based on WY1999. The water volume removed by dredging is a 10-year average. The same water volumes for these inputs and exports were used in both water budget periods.

(b) “Other Small Drainages to Delta" include the following areas shown on Figure 6.1, for which total mercury and TSS concentration data are not available: Dixon, Upper Lindsay/Cache Slough, Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.

Table 6.2: Methylmercury Concentrations and Loads to the Delta for WY2000-2003.

	Average Annual Load (g/yr)	% All MeHg	Average Aqueous Concentration (ng/l)
Tributary Sources			
Sacramento River @ Freeport	2,026	41%	0.103
Yolo Bypass (a)	537	11%	0.424
San Joaquin River near Vernalis	356	7.2%	0.160
Mokelumne River near I-5	108	2.2%	0.166
Calaveras River (b)	25	0.51%	0.144
French Camp Slough (b)	11	0.22%	0.142
Bear/Mosher Creeks (b)	11	0.22%	0.310
Ulatis Creek (b)	8.9	0.18%	0.240
Morrison Creek (b)	8.1	0.16%	0.102
Marsh Creek @ Highway 4 (c)	1.9	0.04%	0.255
Other Small Drainages to Delta	*unknown*		
Sum of Tributary Sources	**3,093**	**63%**	**- - -**
Within-Delta Sources			
Sediment Flux from Wetland Habitats	767	16%	- - -
Sediment Flux from Open Water Habitats	716	15%	- - -
Wastewater (d)	194	3.9%	<0.02 to 1.689
Agricultural Lands	123	2.5%	0.352
Urban	21	0.43%	0.241
Atmospheric Deposition	8.5	0.17%	- - -
Sum of Within-Delta Sources	**1,830**	**37%**	**- - -**
TOTAL MeHg INPUTS:	**4,922 g/yr (4.9 kg/yr)**		

(a) The Yolo Bypass load is based on average MeHg concentrations in Prospect Slough when the Lisbon Weir had a net outflow.
(b) Average wet weather methylmercury concentrations are shown for the small watersheds rather than average annual concentrations.
(c) Only WY2001-2003 flow data were available for Marsh Creek.
(d) Wastewater MeHg loads are based on MeHg concentration data and discharge volumes observed in 2004-2005, while the river and within-Delta nonpoint source loads are based on WY2000-2003, a relatively dry period. Wastewater loads could represent a smaller fraction of the MeHg loading to the Delta during wet years.

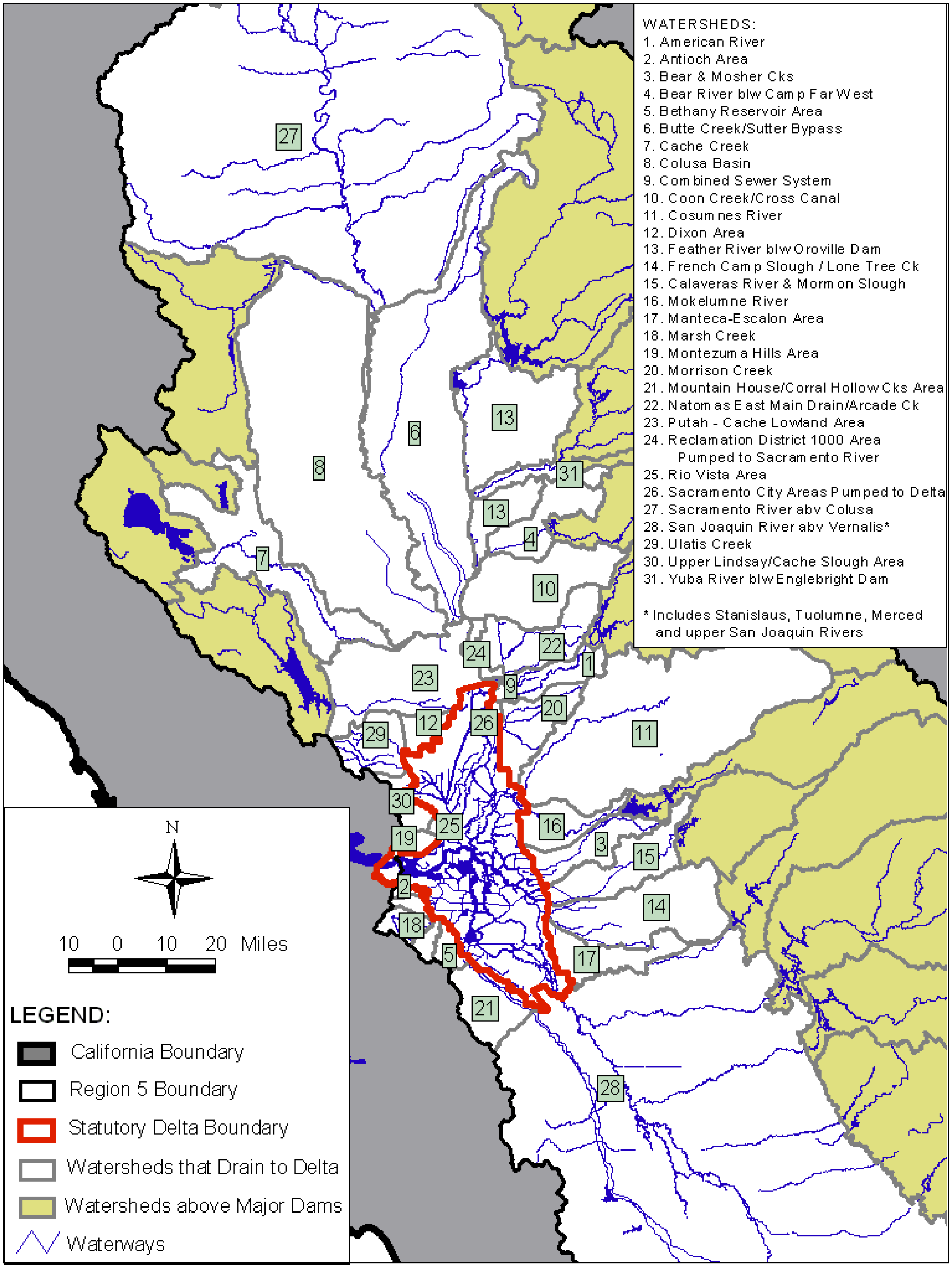

Figure 6.1: Watersheds that Drain to the Delta.

Figure 6.2 shows the tributary methylmercury monitoring locations. Figure 6.3 and Table 6.3 summarize the available methylmercury concentration data for tributary sources. Regressions between methylmercury concentration and daily flow were evaluated for each tributary input to determine whether concentrations could be predicted from flow (Appendix F). Only the regression for the Sacramento River was significant ($P<0.05$). The Sacramento River regression explained 12% of the variation in methylmercury concentrations. Lack of a relationship between methylmercury concentrations and flow at all sites except the Sacramento River suggests that flow is unlikely to be a useful surrogate for methylmercury concentrations. The relationship at Freeport may be a statistical anomaly. Therefore, average methylmercury concentrations were used to estimate all tributary loads. For tributary inputs with a monthly sampling frequency (Table 6.3), concentration data were pooled by month to calculate monthly average concentrations for WY2000-2003 (Appendix F). The monthly average concentrations were multiplied by monthly average flow volumes to estimate loads; monthly loads were summed to calculate an annual average methylmercury load for WY2000-2003. For all the tributaries with less frequent sampling, loads were estimated by multiplying average annual water volume for WY2000-2003 (Table 6.1) by the average wet weather methylmercury concentration for each tributary input (Table 6.3). Although sampling took place on a regular basis at Prospect Slough in the Yolo Bypass, only five sampling events occurred when there was net advective outflow at the Lisbon Weir (Appendix E, Section E.2.2). Dispersive or tidal flows also transport loads from the Bypass below the Lisbon Weir during almost all times; however, the actual amount is unknown at present. Therefore, loads from the Yolo Bypass were estimated by multiplying average methylmercury concentrations observed when the Yolo Bypass had net outflow (0.424 ng/l) by the annual average net advective outflow (1.0 M acre-ft/yr). The resulting loads probably underestimate export from the Bypass.

The Sacramento River was the primary tributary source of methylmercury (2.0 kg/yr) during WY2000-2003 (Table 6.2). LWA (2002) calculated an annual average methylmercury load of 3.2 ±1.6 kg/yr for the Sacramento River at Freeport for 1980-1999 (a wetter period than the TMDL base period). Foe (2002) also concluded that the Sacramento River was the major methylmercury tributary source in all months between March 2000 and September 2001, except for March 2000 when the Yolo Bypass was flooded and it became the primary source of methylmercury. Water years 2000 through 2003 were considered normal to dry years in the Sacramento and San Joaquin watersheds (Appendix E, Section E.1). Therefore, tributary loads for the TMDL study period may underestimate long-term values. In particular, the Yolo Bypass may provide a more substantial methylmercury load to the Delta when flooded for prolonged periods, as in 1997 and 1998.

The Central Valley Water Board is continuing to monitor methylmercury on all major tributary inputs to the Delta. The results will be compiled and a report written in the fall of 2006.

6.2.2 Within-Delta Sediment Flux

Within-Delta sediment flux is estimated to contribute about 30% of the overall methylmercury load (Table 6.2). Methylmercury loads from bottom sediment in open water were estimated from flux rates measured by Gill and others (2003). Wetland flux rates were from Heim, Sassone and others (Heim *et al.*, 2004; Sassone *et al.*, 2004) and a load calculation method outlined by Heim and others (Heim *et al.*, 2004; Heim, personal communication). To measure methylmercury flux in open water habitats, Gill and others

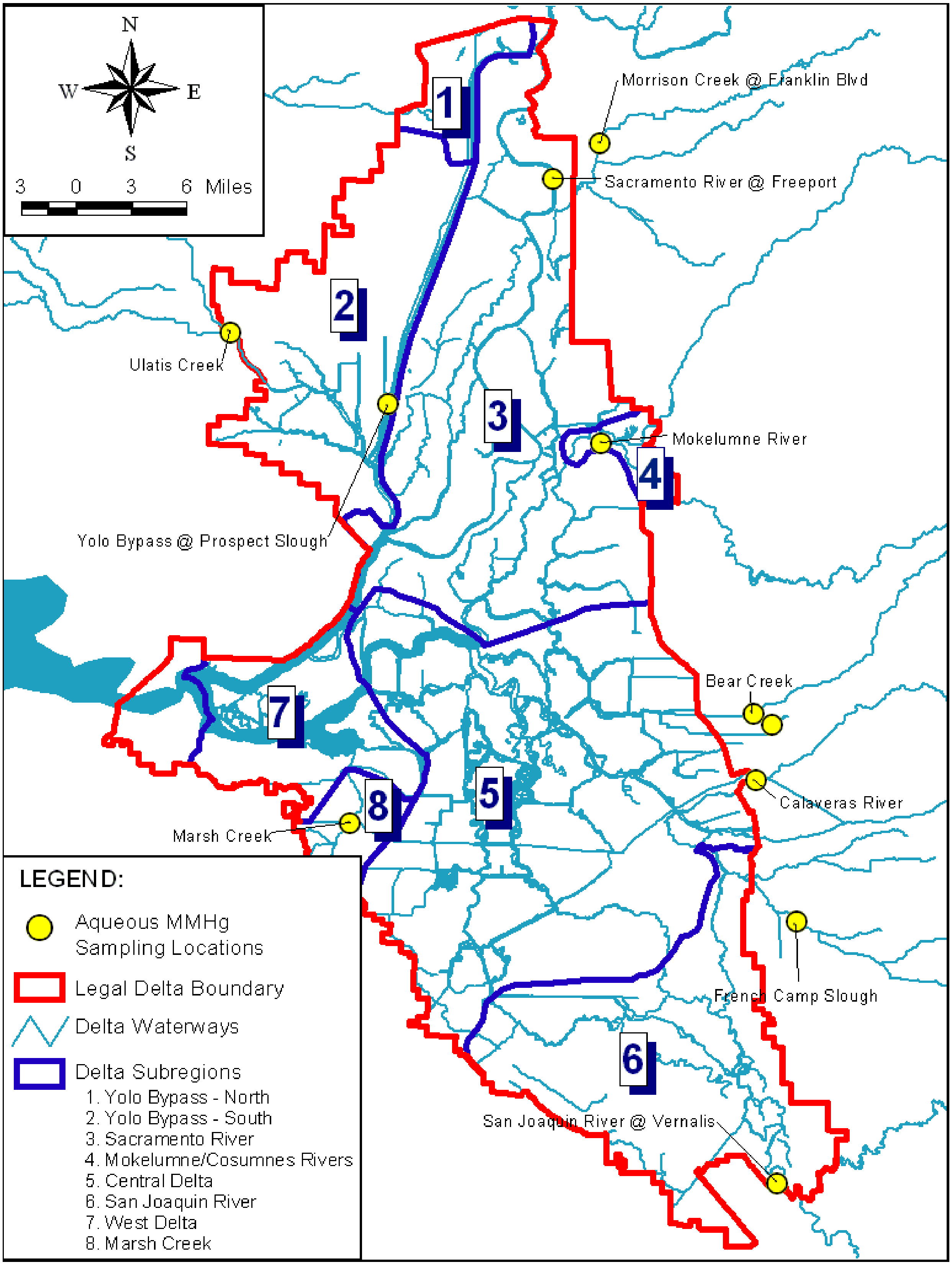

Figure 6.2: Tributary Aqueous Methylmercury Monitoring Locations

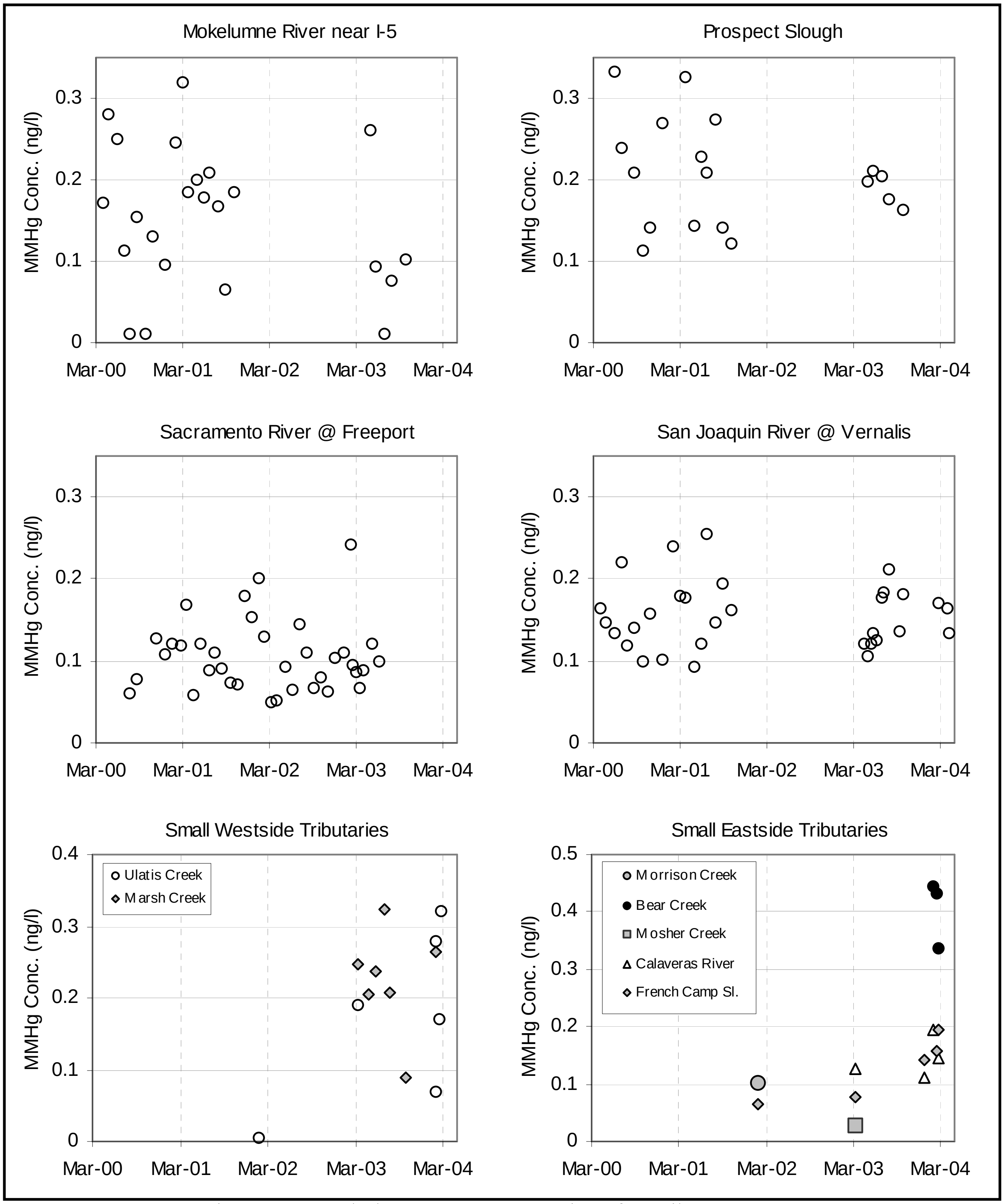

Figure 6.3: Methylmercury Concentrations for Tributary Inputs

Table 6.3: Methylmercury Concentrations for Tributary Inputs

Site	# of Samples	Sampling Begin Date	Sampling End Date	Min. MeHg Conc. (ng/l)	Ave. MeHg Conc. (ng/l)	Annual Ave. MeHg (ng/l) (a)	Median MeHg Conc. (ng/l)	Max. MeHg Conc. (ng/l)
Large Tributaries to the Delta								
Mokelumne River @ I-5	23	3/28/00	9/30/03	0.011	0.153	0.166	0.167	0.320
Prospect Slough (Yolo Bypass) (b)	22 (5)	3/28/00	9/30/03	0.114 (0.197)	0.256 (0.424)	0.273 (0.424)	0.209 (0.413)	0.701 (0.701)
Sacramento River @ Freeport	36	7/18/00	6/11/03	0.050	0.105	0.103	0.097	0.242
San Joaquin River @ Vernalis	31	3/28/00	4/12/04	0.093	0.156	0.160	0.147	0.256
Small Tributaries to the Delta								
Bear Creek @ West Lane	3	2/2/04	2/26/04	0.336	0.404	0.310	0.431	0.446
Calaveras River @ RR u/s West Lane	4	3/15/03	2/26/04	0.110	0.144	0.144	0.137	0.193
French Camp Slough d/s Airport Way	5	1/28/02	2/26/04	0.063	0.127	0.142	0.143	0.193
Marsh Creek @ Hwy 4	7	3/15/03	2/2/04	0.090	0.224	0.255	0.237	0.323
Morrison Creek @ Franklin	1	1/28/02	1/28/02	0.102	0.102	0.102	0.102	0.102
Mosher Creek @ Morada Lane (c)	1	3/15/03	3/15/03	0.028	0.028	(c)	0.028	0.028
Ulatis Creek near Main Prairie Rd	6	1/28/02	2/26/04	0.004	0.172	0.240	0.180	0.322

(a) For the large tributary inputs, methylmercury concentration data were pooled by month to estimate monthly average methylmercury concentrations and loads (Tables Q.1 and Q.2); the monthly average loads were summed to estimate annual average methylmercury loads for water years 2000-2003. The methylmercury concentration data are listed in Table D.1 in Appendix D. The monthly average concentrations and flows are listed in Appendix F. The monthly average concentrations were averaged to estimate annual average concentrations, which were included in Table 6.2. Sampling on the small tributaries did not take place monthly. In addition, flow gages were unavailable for these tributaries. Therefore, wet weather methylmercury concentration data were averaged to estimate annual average methylmercury concentrations and loads.

(b) Only five Prospect Slough MeHg sampling events took place when there was a net outflow. These sampling events are described in parentheses. Methylmercury concentrations during other times were strongly affected by tidal pumping of waters from the Sacramento River.

(c) The one Mosher Creek sample result was combined with the Bear Creek methylmercury data to estimate methylmercury loads for both creeks.

(2003) deployed benthic flux chambers at nine locations in the Bay-Delta region during five separate field-sampling efforts between May 2000 and October 2001. This study estimated a methylmercury flux rate of approximately 10 ng/m^2/day for open water habitat. An additional study of sediment-water MeHg flux within marsh and wetland habitat was conducted at two experimental ponds on Twitchell Island (Heim *et al.*, 2004; Sassone *et al.*, 2004). The pond with more shallow water and greater coverage of emergent vegetation had sediment-water flux rates of 41 ng/m^2/day and 3 ng/m^2/day during June and October 2003, respectively. Heim (personal communication) recommended that these flux rates be used to estimate warm and cool season loads; the warm season was defined as March through September (214 days) and the cool season as October through February (151 days).

Wetland and open water acreages were estimated using the 1997 National Wetland Inventory coverage for the Delta region (Figure 6.4). Types of wetland habitat in the Delta are predominantly seasonal wetlands and tidal, salt, brackish and freshwater marshes. The open-water, warm season wetland and cool season wetland flux rates were multiplied by the open water and wetland areas, respectively, to estimate daily loading. The daily loads were multiplied by the number of days in the warm and cool seasons and then summed to estimate annual loading. The loads to each Delta subarea were calculated (Table 6.4) to develop subarea-specific allocations (Chapter 8). The Yolo Bypass subarea has the greatest methylmercury loading from sediment because it has the greatest acreage of wetlands; the Central Delta subarea is second because it has the greatest amount of open water habitat. Sediment loading for each subarea was summed so that a Delta-wide sediment load could be compared with other sources in Table 6.2.

Texas A&M and Moss Landing Marine Laboratory are conducting additional benthic loading studies to better define methylmercury sediment flux rates from different types of wetlands and other habitats. The results of these studies should become available in the fall/winter of 2006.

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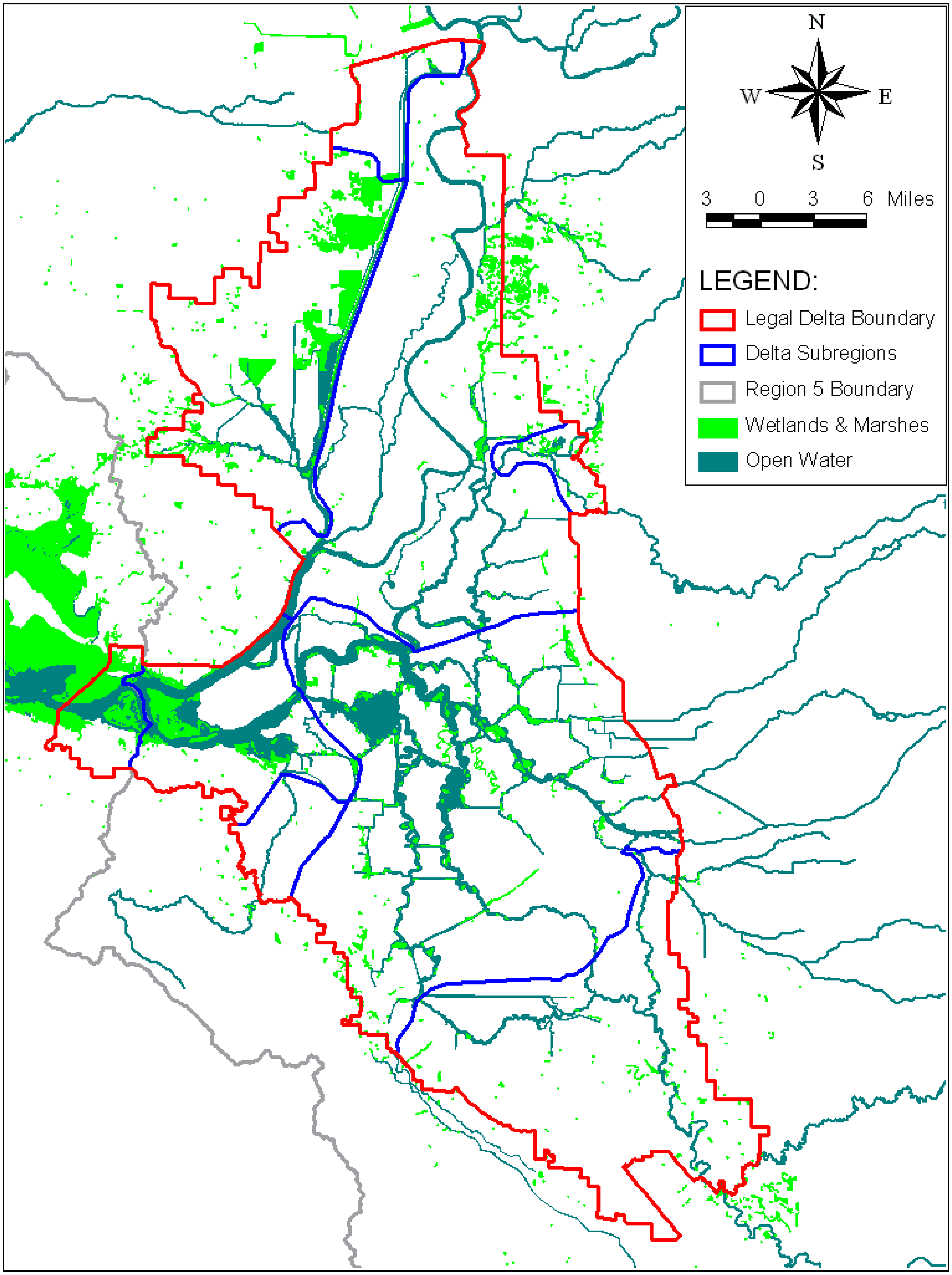

Figure 6.4: Delta Wetlands and Open Water Habitat. Wetland areas include seasonal wetlands and brackish and freshwater marshes. (Wetland and open water coverage source: NWI, 1997. This figure does not include wetlands to the east of the Delta.)

Table 6.4: Methylmercury Loading from Wetland and Open Water Habitats in Each Delta Subarea. (a)

	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass-North	Yolo Bypass-South	Grand Total
Open Water Habitats									
Open Water (acres):	20,402	77	2.2	7,973	1,325	12,833	665	5,162	**48,439**
% of Total Water Area	*42%*	*0.2%*	*0.00%*	*16%*	*2.7%*	*26%*	*1.4%*	*11%*	***100%***
Open Water (m2):	82,564,182	313,064	9,057	32,264,813	5,364,032	51,931,998	2,690,703	20,890,049	**196,027,898**
Daily Open Water MeHg Load (g/day) (b):	0.8	0.0031	0.0001	0.32	0.05	0.52	0.03	0.21	**2.0**
Annual Open Water MeHg Load (g/year):	301	1.1	0.03	118	20	190	10	76	**716**
Wetland Habitats (c)									
Wetland Area (acres):	3,663	324	11	1,786	478	3,271	377	10,832	**20,743**
% of Total Wetland Area	*18%*	*1.6%*	*0.05%*	*8.6%*	*2.3%*	*16%*	*1.8%*	*52%*	***100%***
Wetland Area (m2):	14,822,447	1,312,118	43,666	7,229,269	1,936,349	13,237,507	1,524,382	43,837,692	**83,943,430**
Warm Season MeHg Daily Load (g/day):	0.60	0.05	0.002	0.29	0.08	0.54	0.06	1.8	**3.4**
Cool Season MeHg Daily Load (g/day):	0.044	0.004	0.0001	0.022	0.006	0.040	0.005	0.13	**0.25**
Annual Wetland MeHg Load (g/year):	135	12.0	0.40	66	18	121	14	401	**767**
Annual MeHg Load (grams/year):	**437**	**13**	**0.43**	**184**	**37**	**311**	**24**	**477**	**1,483**

(a) Wetland and open water habitat acreages were obtained from the National Wetland Inventory (NWI, 1997).
(b) The daily open water MeHg load for each Delta subarea was estimated by multiplying its open water area by the open water sediment flux rate, 10 ng/m2/day. The open water MeHg flux rate was developed by Gill and others using benthic flux chambers (Gill *et al.*, 2003).
(c) The daily warm season and cool season wetland MeHg loads for each Delta subarea were estimated by multiplying the open water area by the warm and cool season wetland flux rates, 41 ng/m2/day and 3 ng/m2/day. The warm and cool season wetland flux rates were developed by Heim and others (2004) using direct measurement of MeHg concentrations in inflows and outflows from test wetlands on Twitchell Island in the west Delta. The warm season for the wetland flux rate is defined approximately as March through September (214 days) and the cool season is defined approximately as October through February (151 days) (Heim, personal communication). The annual load was estimated by multiplying the number of days in the warm and cool seasons by the daily warm and cool season loads, respectively, and summing the resulting seasonal loads.

6.2.3 *Municipal & Industrial Sources*

Twenty NPDES-permitted municipal and industrial dischargers are located in the Delta (Figure 6.5, Table 6.5). These facility discharges account for about 4% of the annual methylmercury loading to the Delta (Table 6.2). Information on the facilities is from the State Water Resources Control Board's Surface Water Information (SWIM) database. Information on average flows rates for each facility was obtained from the Central Valley Water Board's discharger project files and permits. Appendix G provides additional information about the facilities.

Between December 2000 and December 2001, the Sacramento Regional County Sanitation District (SRCSD) collected 45 samples to characterize its effluent methylmercury levels. In February and March 2004, Central Valley Water Board staff conducted two sampling events at four municipal wastewater treatment plants (WWTPs)[32] to determine whether the SRCSD data are representative of other municipal wastewater treatment plants' effluent methylmercury levels. The 2004 sampling results indicated that the methylmercury data from the SRCSD facility may not be representative of other facilities in the Delta region. Therefore, the Central Valley Water Board issued a California Water Code Section 13267 order in July 2004 requiring municipal WWTPs and other dischargers located in the Delta and downstream of major dams in the Delta's tributary watersheds to monitor and characterize their effluent. Table 6.5 summarizes the results of available methylmercury data for facility discharges in the Delta. Appendix G provides a preliminary summary of the methylmercury data generated by sampling efforts throughout the Delta and its tributary watersheds to date. Appendix H provides a copy of the letter and a list of facilities that received the Section 13267 order.

Thirteen of the Delta facilities are municipal wastewater treatment plants. Average annual methylmercury loads were calculated for each municipal WWTP using the average MeHg concentration based on available data and the annual discharge volume for 2005. Facility-specific average effluent MeHg concentrations ranged from less than 0.02 ng/l (Brentwood and Deuel Vocational Institute WWTPS) to 1.9 ng/l (SRCSD Walnut Grove WWTP). The variability in the MeHg concentrations observed in effluent from different municipal WWTPs in the Delta is comparable to WWTP effluent concentrations observed elsewhere. A study that evaluated MeHg concentrations in three domestic sewage treatment plants at the City of Winnipeg, Canada, found average effluent MeHg concentrations to be very low at two facilities (0.13 to 0.56 ng/l, no seasonal trend) and higher at a third (greater than 2 ng/l, with highest concentrations in the summer) (Bodaly *et al*., 1998). A separate study that evaluated seasonal patterns in sewers and wastewater unit processes in the Onondaga County Metropolitan Wastewater Treatment Plant in Syracuse, New York, observed a mean MeHg concentration of 1.63 ± 1.19 and 1.43 ± 0.671 ng/l[33] in warm and cool months, respectively; a peak of 3.70 ng/l was measured in May (McAlear, 1996). Cool weather sampling at the San Jose/Santa Clara Water Pollution Control Plant in California indicated an average effluent MeHg concentration of 0.029 ng/l (n=16) (City of San Jose, 2005).

[32] Central Valley Water Board staff also conducted sampling at one power plant. The Mirant Delta Contra Costa Power Plant withdraws San Joaquin River water for use as cooling water and discharges back to the San Joaquin River. Central Valley Water Board staff selected this plant for methylmercury sampling for two reasons: (1) to determine if the use of ambient water for cooling water caused any measurable increase in methylmercury levels, and (2) because the plant has the largest daily and annual discharge volume in Region 5. Based on the comparison of intake and outfall data, Mirant Delta's Contra Costa Power Plant did not appear to be a source of new methylmercury to the Delta (Table G.5b).

[33] Mean concentration ± standard deviation.

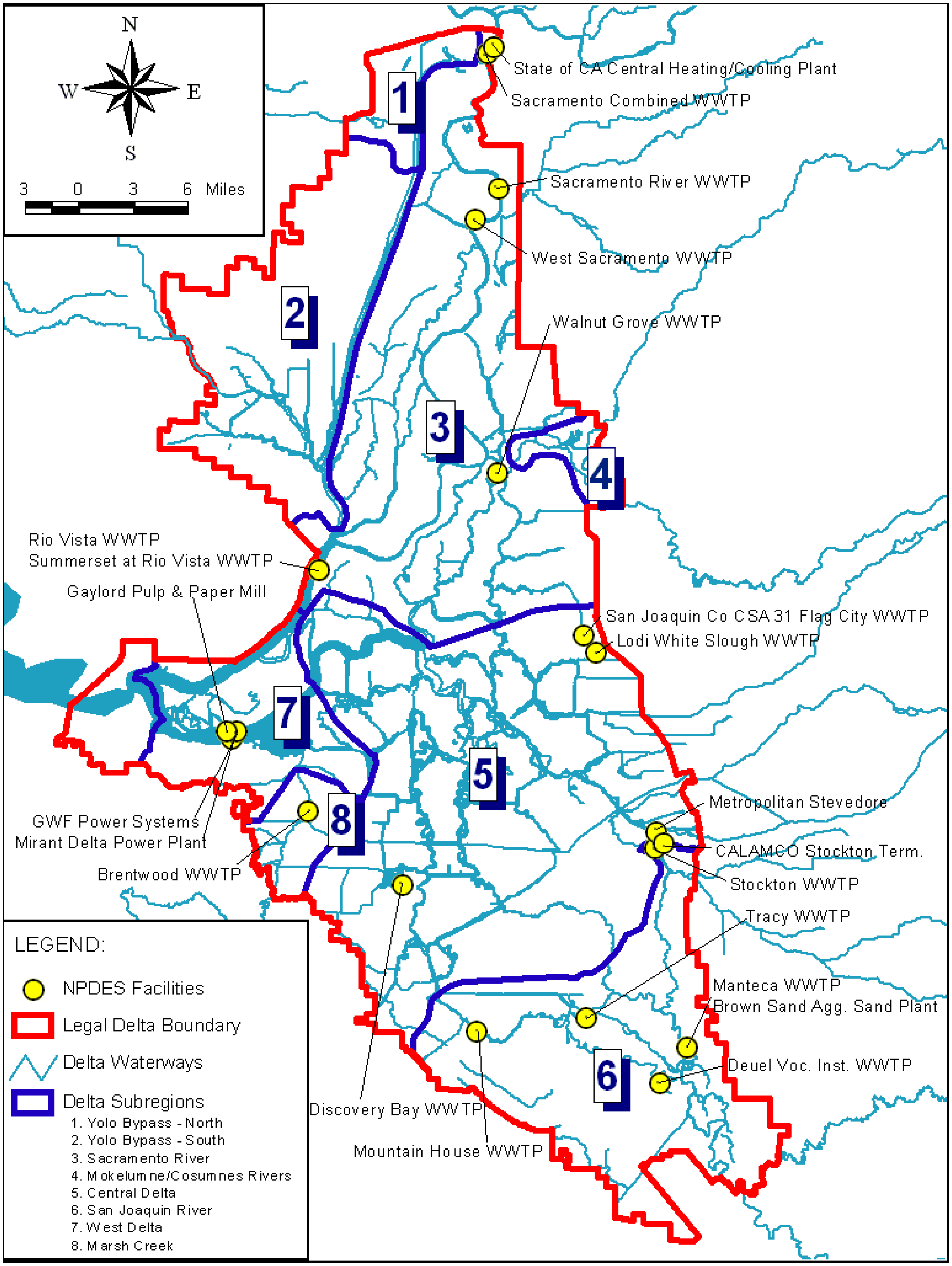

Figure 6.5: NPDES Facilities within the Statutory Delta Boundary.

Table 6.5: Summary of Unfiltered Methylmercury Concentration Data for Effluent from NPDES-permitted Facilities in the Delta. (a)

Facility Name	NPDES #	Facility Type	Delta Subarea	# of MeHg Sampling Events	Average Conc. (ng/l) (b)	Conc. Range	# of Nondetect Results	MeHg Sampling Period	Average Daily Discharge for WY2005 (mgd)	Annual MeHg Load (g/yr)
Brentwood WWTP	CA0082660	POTW	Marsh Ck	13	0.02	0.02-0.02	13	8/04-8/05	3.09	0.043
CALAMCO Stockton Terminal	CA0083968	Heating /Cooling	Central	4	0.29	0.030-0.919	0	8/04-8/05	5.06	2.0 (c)
Deuel Vocational Institute WWTP	CA0078093	POTW	San Joaquin	4	0.02	0.02-0.02	4	10/04-6/05	0.47	0.0064
Discovery Bay WWTP	CA0078590	POTW	Central	12	0.20	0.025-2.03	7	8/04-7/05	1.54	0.41
GWF Power Systems	CA0082309	Power	West	4	0.03	0.025-0.025	4	8/04-5/05	0.05	0.00081 (c)
Lodi White Slough WWTP	CA0079243	POTW	Central	12	0.13	0.02-1.24	4	8/04-7/05	3.97	0.70
Manteca Aggregate Sand Plant	CA0082783	Lake Dewatering	San Joaquin	2	0.03	0.02-0.043	1	8/04-11/04	9.15	0.34
Manteca WWTP	CA0081558	POTW	San Joaquin	11	0.22	0.037-0.356	0	9/04-7/05	4.63	1.4
Mirant Delta LLC Contra Costa Power Plant (Outfall 1)	CA0004863	Power	West	12	0.07	0.02-0.121	1	2/04-5/05	2.90	0.30 (c)
Mirant Delta LLC Contra Costa Power Plant (Outfall 2)	CA0004863	Power	West	10	0.09	0.042-0.15	0	2/04-3/05	121.03	14 (c)
Rio Vista WWTP	CA0079588	POTW	Sacramento	4	0.16	0.035-0.522	0	8/04-4/05	0.47	0.11
Rio Vista Trilogy WWTP	CA0082848	POTW	Sacramento						0.10	Tbd
San Joaquin Co DPW CSA 31 Flag City WWTP	CA0082848	POTW	Central	3	0.09	0.025-0.152	1	1/05-10/05	0.06	0.0065
SRCSD Sacramento River WWTP	CA0077682	POTW	Sacramento	45	0.73	0.144-2.93	0	12/00-12/01	151.42	152
SRCSD Walnut Grove WWTP	CA0078794	POTW	Sacramento	3	1.69	0.759-3.36	0	12/04-4/05	0.08	0.19
State of California Central Heating/Cooling Plant	CA0078581	Heating /Cooling	Sacramento	4	0.02	0.02-0.029	3	8/04-6/05	5.26	0.11 (c)
Stockton WWTP	CA0079138	POTW	San Joaquin	12	0.94	0.02-2.09	1	8/04-7/05	27.78	36
Tracy WWTP	CA0079154	POTW	San Joaquin	13	0.15	0.025-0.422	1	8/04-8/05	9.49	1.9
West Sacramento WWTP	CA0079171	POTW	Sacramento	12	0.05	0.02-0.085	1	8/04-7/05	5.60	0.39

(a) No methylmercury data are yet available for Metropolitan Stevedore (CA0084174), a power facility in the Central Delta subarea, and the Sacramento Combined WWTP (CA0079111; see Table G.2 in Appendix G) in the Sacramento River subarea. In addition, Mountain House CSD WWTP (CA0084271) is not yet discharging to surface water.

(b) Analytical method detection limits were 0.025 ng/l or less. One half the detection limit was used for nondetect values to calculate the average methylmercury concentrations and loads.

(c) Based on the comparison of the available intake and outfall methylmercury data (Table G.4 in Appendix G), power and heating/cooling facilities that use ambient water for cooling water do not appear to act as a source of new methylmercury to the Delta. This assumption will be re-evaluated as additional information becomes available.

Some type of seasonal or other treatment-related variability was observed in effluent methylmercury concentrations at several of the municipal WWTPS in the Delta and its tributary watersheds (e.g., Anderson, Chico, Davis, Manteca, SRCSD Sacramento River, Stockton, Tracy and Yuba City WWTPs; see Figures G.2 and G.3 in Appendix G). Identifying the reasons why some facilities discharge effluent with higher methylmercury concentrations than others, and why some facilities have seasonal or other treatment-related variability in their methylmercury discharges, could be critical components to the development of methylmercury controls.[34]

Five of the facilities in the Delta are power or heating/cooling facilities that use ambient water for cooling water. Based on the comparison of the available intake and outfall methylmercury data (Table G.4 in Appendix G), the facilities do not appear to act as a source of new methylmercury to the Delta. This assumption will be re-evaluated as additional information becomes available.

The Manteca Aggregate Sand Plant NPDES permit (CA0082783) allows flood-control pumping from Oakwood Lake, a former excavation pit filled primarily by groundwater, to the San Joaquin River. The results from discharge sampling in August and November 2004, nondetect (<0.02 ng/l) and 0.043 ng/l respectively, are comparable to groundwater treatment plant discharges in the Delta's tributary watersheds (refer to Table G.3 in Appendix G) and are substantially lower than the monthly average methylmercury concentrations observed in the San Joaquin River at Vernalis during August and November (0.167 and 0.130 ng/l, respectively; refer to Table F.1 in Appendix F). Average annual methylmercury loading from Oakwood Lake was estimated using a methylmercury concentration of 0.03 ng/l and the average annual discharge volume.

The City of Sacramento owns and operates a combined sewer system (CSS) that serves about eleven thousand acres. The CSS conveys up to 60 mgd of domestic and industrial wastewater and storm runoff to the SRCSD's Sacramento River WWTP. The City of Sacramento operates its Combined Wastewater Treatment Plant (CA0079111) only when combined wastewater/storm flows exceed 60 mgd (Table G.2 in Appendix G). The plant provides primary treatment with disinfection. The CSS discharges to receiving waters only when storm flows exceed total treatment and storage capacity. Discharges are predominantly urban storm runoff. No methylmercury data are available yet for Combined Wastewater Treatment Plant or untreated CSS discharges. Therefore, the average methylmercury concentration in wet weather urban runoff (0.241 ng/l, see Section 6.2.5) and average annual discharge volume (464 million gallons/year, see Table G.2b) were used to estimate a CSS methylmercury load of 0.43 g/yr.

[34] In addition, seasonal increases in effluent methylmercury loading from some facilities could result in a greater influence on local water bodies. For example, SRCSD Sacramento River WWTP (the largest permitted facility discharge in the Central Valley) has an annual effluent methylmercury load (151 g/yr, see Table 6.5) that averages about 8% of its receiving water load (2,026 g/yr, Sacramento River at Freeport, see Table 6.2). During the wet season, SRCSD daily effluent loads ranged between 2 and 12% of river loads, and daily effluent volumes averaged about 2% of river volume (Table G.4 in Appendix G). However, during the dry season, SRCSD daily effluent loads ranged between 16 and 30% of river loads while effluent volume remained about 2% of river volume. Currently, little is known about the seasonal exposure regime controlling methylmercury concentrations in aquatic biota. Therefore, this TMDL is based on annual average source loads to weight all seasons equally. However, studies are planned to better determine the seasonal exposure regime when most of the methylmercury is sequestered in the aquatic food chain; results from these studies may lead to future revisions in the TMDL. Seasonal discharge information is not yet available for most methylmercury sources to the Delta, but would be required by the source control and characterization studies proposed by the draft implementation plan described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report.

6.2.4 Agricultural Return Flows

More than half a million acres of the Delta islands are under agricultural production (Figure 6.6). Water seeps and is diverted onto the islands for irrigation from the surrounding river channels. The unused water is returned to Delta waterways via a series of main drains. Many of the islands are predominately peat, a substance that Gill and others (2003) and Heim and others (2003) have shown to be a good substrate for methylmercury production. Water samples collected from five Delta Island main drains in June and July 2000 suggest that the agricultural islands are net exporters of unfiltered methylmercury (Foe, 2003). Methylmercury concentrations were variable but high compared to concentrations in the river channels surrounding the islands from which the irrigation supply water was diverted and unused tail-water returned. Agricultural return flow concentrations averaged 0.35 ng/l in June and July 2000 while concentrations in the supply water was 0.07 ng/l (Tables 6.6 and 6.7). This translates to a net production rate of approximately 17 to 35 grams per month (~0.5 to 1.1 g/day) if occurring over the entire Delta or 10 to 25% of all river loading in the two-month period.

The annual methylmercury load from agricultural lands located in the Delta was estimated to be 123 g/yr (Table 6.2). Delta agricultural diversion and return flow estimates were obtained from the Delta Island Consumptive Use Model for water year 1999, the year during which the majority of agricultural drain methylmercury data were collected (Table 6.8). The annual diversion and return flow water volumes were multiplied by their respective methylmercury concentrations to estimate annual loads. For this preliminary evaluation, the average of available agricultural drain methylmercury data (Table 6.6) was used to estimate methylmercury concentrations in all Delta agricultural return flows. The methylmercury concentration of river diversions was estimated by averaging monthly Sacramento River and State Water Project MeHg concentrations between May and December (Appendix D, Table D.3). To estimate the methylmercury loading from agricultural lands, the estimated methylmercury load in the river waters diverted onto the islands was subtracted from the agricultural return loads (Table 6.6), resulting in a net input of 123 grams per year. This load was multiplied by the percentage of total agricultural acreage located in each Delta subarea to estimate a subarea specific loading rate (Table 6.9). The Central Delta and Sacramento River subareas have the greatest estimated methylmercury loading from agricultural lands because they have the largest acreage of agricultural land.

This preliminary evaluation indicates that agricultural runoff may contribute about 2.5% of the methylmercury load to the Delta. However, Central Valley Water Board staff recognizes that agricultural loads have not been adequately characterized. Staff recommends that a follow-up study be undertaken to more fully monitor and characterize loads from Delta Islands and, if elevated, determine the primary land uses responsible for methylmercury production. The study should be done in cooperation with agricultural interests in the Delta.

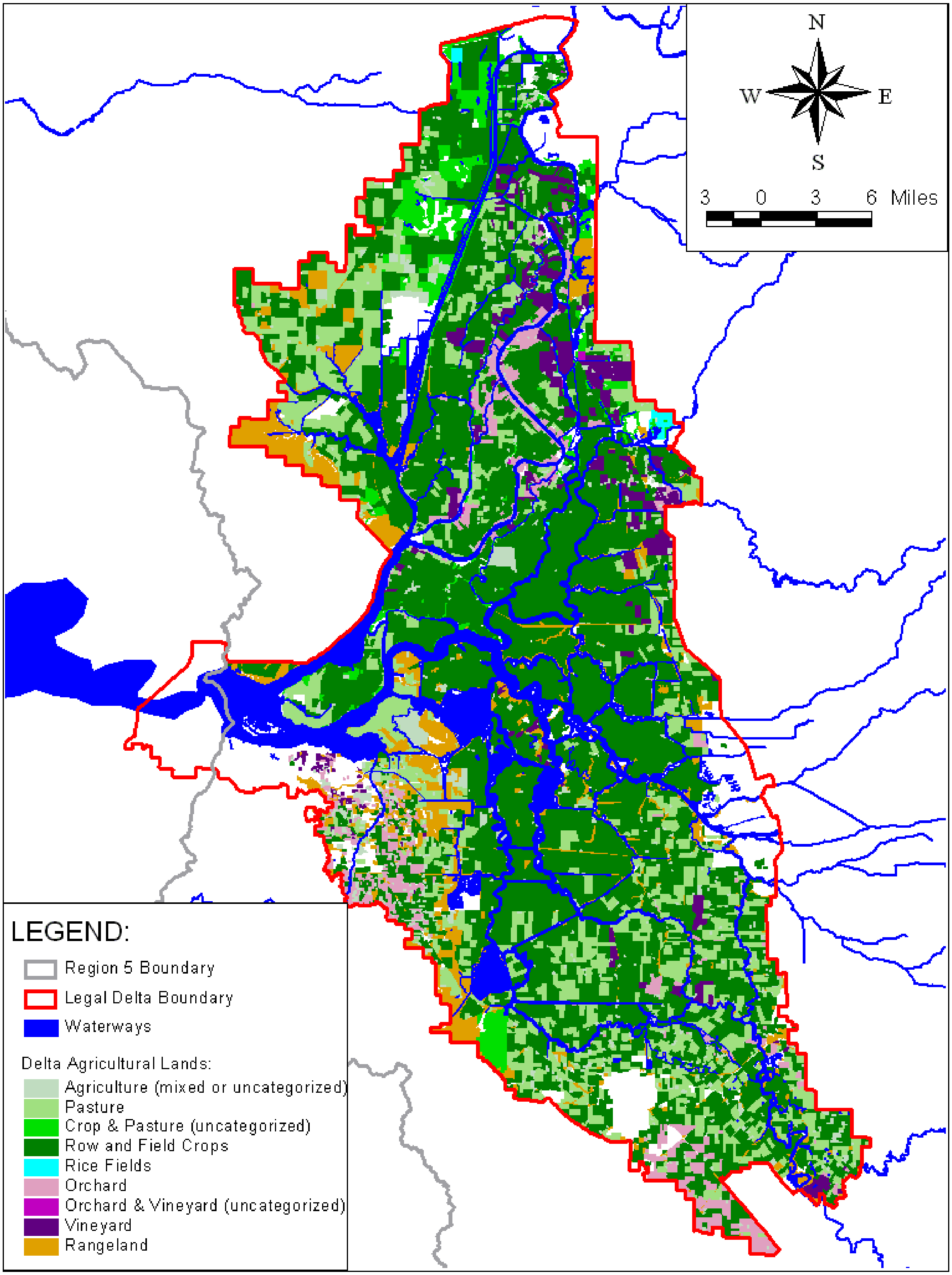

Figure 6.6: Agricultural Lands within the Statutory Delta Boundary.
(Agricultural land uses outside the Delta are not shown.)

Table 6.6: Values Used to Estimate MeHg Loads from Agricultural Lands

	Average MeHg Conc. (ng/l) (a)	**Flow** (af/yr) (b)	**MeHg Load** (g/yr)
Diversions:	0.071	1,597,880	139
Ag Drain Returns:	0.352	603,546	262
Net Ag Drain Input (g/yr):			**123**

(a) Average agricultural drain methylmercury concentration obtained from Table 6.7. Average methylmercury concentration for diversion flows was estimated by averaging monthly Sacramento River and State Water Project MeHg concentrations during May through December (Appendix D).
(b) Estimated annual average agricultural diversion and return flows were obtained from Table 6.6.

Table 6.7: Delta Agricultural Main Drain Methylmercury Concentration Data (a)

Site	**Sample Date**	**MeHg Conc. (ng/l)**
Empire Tract Main Drain	6/26/00	0.093
Empire Tract Main Drain	7/19/00	0.117
Lower Jones Main Drain	6/26/00	0.302
Staten Island Main drain	6/26/00	0.198
Staten Island Main drain	7/19/00	0.094
Twitchell Island Main Drain	6/26/00	0.387
Twitchell Island Main Drain	7/19/00	1.500
Twitchell Island Main Drain	6/30/03	0.292 (b)
Twitchell Island Main Drain	7/28/03	0.341
Twitchell Island Main Drain	8/27/03	0.609
Twitchell Island Main Drain	9/25/03	0.157 (b)
Upper Jones Main Drain	7/19/00	0.131

(a) Source: Foe, 2003; Central Valley Water Board sampling, 2003.
(b) Average of laboratory replicates (0.289 and 0.294 ng/l on 6/30/03 and 0.147 and 0.167 ng/l on 9/25/03).

Table 6.8: Delta-wide Island Consumptive Use Estimates - Water Year 1999 (acre-feet) (a)

Period	Diversions + Seepage	Return Flow	Net Channel Depletion
Oct-98	92,969	36,155	56,815
Nov-98	74,202	34,988	39,213
Dec-98	81,348	31,359	49,989
Jan-99 (b)	*42,180*	*111,661*	*-69,481*
Feb-99 (b)	*34,044*	*120,960*	*-86,916*
Mar-99	57,306	43,410	13,896
Apr-99	108,000	46,532	61,468
May-99	193,317	67,944	125,373
Jun-99	273,838	92,648	181,190
Jul-99	353,800	120,147	233,653
Aug-99	221,540	77,167	144,373
Sep-99	141,560	53,197	88,364
Annual Totals (b)	**1,597,880**	**603,546**	**994,334**

(a) Diversion and flow volumes were obtained from the Delta Island Consumptive Use Model (Suits, 2000).
(b) Only months with positive depletion were used in the annual methylmercury load estimates because during Jan-Feb there is (1) substantial return flow resulting from rainfall, which is assumed to contain no methylmercury, and (2) no methylmercury concentration data were available for the agricultural return drains during the coolest/wettest months.

Table 6.9: Agricultural Acreage and Methylmercury Load Estimates by Delta Subarea

	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass-North	Yolo Bypass-South	**TOTAL**
Acreage (a)	157,035	6,790	9,362	155,532	96,874	17,313	11,046	70,523	**524,474**
% of Total Acreage	30%	1.3%	1.8%	30%	18%	3.3%	2.1%	13%	**100%**
Estimated Annual MeHg Load (g/year) (b)	36.8	1.6	2.2	36.4	22.7	4.1	2.6	16.5	**123**

(a) Land cover source: DWR land use GIS coverages (1993-2003).
(b) A Delta-wide agricultural land methylmercury loading of 123 g/yr was estimated using the information presented in Tables 6.6 through 6.8. The Delta-wide load was multiplied by the percentage of total agricultural acreage located in each Delta subarea to estimate the amount of loading from agricultural lands in each subarea.

6.2.5 Urban Runoff

Approximately 60,000 acres of the land in the Delta is classified as urban (DWR, 1993-2003). Most of the urban area is regulated by waste discharge requirements under the National Pollutant Discharge Elimination System (NPDES), which permits discharge of storm water from municipal separate storm sewer systems (MS4s). [35] Table 6.10 lists the permits that regulate urban runoff in the Delta and the amount of urban acreage in each Delta subarea. Figure 6.7 shows their locations. Urban acreages corresponding to each Permittee were estimated from the DWR Land Use coverage (DWR, 1993-2003) using available MS4 service area delineations. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city and county boundaries. Urban areas not encompassed by a MS4 service area were grouped into a "nonpoint source" category within each Delta subarea.

Methylmercury concentration data have been collected by Central Valley Water Board staff and the City and County of Sacramento from several urban waterways in or adjacent to the Delta. Figure 6.8 shows the sampling locations and Figure I.1 in Appendix I illustrates the wet and dry weather concentrations by location. Methylmercury concentrations ranged from a wet weather low of 0.035 ng/l (City of Sacramento Sump 111) to a dry weather high of 2.04 ng/l (Strong Ranch Slough). A visual inspection of the methylmercury data suggests that the differences between urban watersheds are not related to land use. Therefore, the data were averaged by wet and dry weather for each location (Table 6.11). The

[35] A municipal separate storm sewer system (MS4) is a conveyance or system of conveyances that include roads with drainage systems, municipal streets, alleys, catch basins, curbs, gutters, ditches, manmade channels, or storm drains, owned by a State, city, county, town or other public body. MS4s are designed and used for collecting or conveying storm water and do not include combined sewer systems or parts of a publicly owned treatment works. MS4s discharge to Waters of the United States. The Municipal Storm Water Permitting Program regulates storm water discharges from MS4s. MS4 permits were issued in two phases. Under Phase I, which started in 1990, the RWQCBs have adopted NPDES storm water permits for medium (serving between 100,000 and 250,000 people) and large (serving greater than 250,000 people) municipalities. Most of these permits are issued to a group of co-permitees encompassing an entire metropolitan area. These permits are reissued as the permits expire. As part of Phase II, the State Board adopted a General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ, NPDES No. CAS000004) to provide permit coverage for smaller municipalities, including non-traditional small MS4s, which are governmental facilities such as military bases, public campuses, and prison and hospital complexes.

averages of these location-based wet and dry weather averages are assumed to represent runoff from all urban areas in or adjacent to the Delta and were used to estimate loads. These values are similar to methylmercury levels observed during high flow conditions in two urbanized tributaries in the Washington, D.C. region. The urbanized Northeast and Northwest Branches of the Anacostia River had average methylmercury concentrations of 0.12 ± 0.06 ng/l and 0.07 ± 0.07 ng/l, respectively, during base flows, and 0.39 ± 0.21 ng/l and 0.77 ± 0.46 ng/l, during high flows (Mason & Sullivan, 1998).

Average annual urban runoff loading was estimated for WY2000-2003 so that urban runoff loading could be compared to tributary loading (Table 6.2). To estimate wet weather methylmercury loads, the wet weather concentration (0.241 ng/l) was multiplied by the runoff volumes estimated for WY2000-2003 for each MS4 area within each Delta subarea. To estimate dry weather methylmercury loads, the dry weather concentration (0.363 ng/l) was multiplied by the estimated dry weather urban runoff volume. Section E.2.3 in Appendix E describes the methods used to estimate wet and dry weather runoff volumes from urban areas within the Delta. Wet and dry weather methylmercury loads were summed to estimate the average annual loading of 21 grams to Delta waterways. The loading to each Delta subarea (Table 6.12) was used to develop MS4 Permittee and subarea-specific allocations (Chapter 8).

Table 6.10: MS4 Permits that Regulate Urban Runoff within the Delta

Permittee	NPDES # (a)	**Urban Acreage within Delta Subareas** (b)							Total Acreage
		Central Delta	Cosumnes/ Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass	
City of Lathrop	CAS000004					738			**738**
City of Lodi	CAS000004	134							**134**
City of Rio Vista	CAS000004				38				**38**
City of Tracy	CAS000004					5,268			**5,268**
City of West Sacramento	CAS000004				1,715			2,754	**4,470**
County of Contra Costa	CAS083313	2,181		3,427			9,528		**15,135**
County of San Joaquin	CAS000004	1,494	134		521	7,140			**9,288**
County of Solano	CAS000004				184			220	**404**
County of Yolo	CAS000004				200			273	**473**
Port of Stockton MS4	CAS084077	1,067				28			**1,095**
Sacramento Area MS4 (c)	CAS082597				7,975				**7,975**
Stockton Area MS4	CAS083470	10,574				1,481			**12,055**
Urban Nonpoint Source (d)		337	42		1,620	7	65		**2,070**
Total Acreage		**15,786**	**176**	**3,427**	**12,253**	**14,663**	**9,592**	**3,247**	**59,144**

(a) Permittees with NPDES No. CAS000004 are covered under the General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ) adopted by the State Board to provide permit coverage for smaller municipalities (serving less than 100,000 people).

(b) Urban land uses and acreages corresponding to each Permittee were estimated from the DWR Land Use coverage (DWR, 1993-2003) using available service area delineations. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city boundaries.

(c) The Sacramento MS4 Area does not include the Sacramento Combined Sewer System (CSS) service area illustrated in Figure 6.7. The CSS service area is permitted by a separate NPDES permit, which is described in Section 6.2.3 and TableG.2 in Appendix G.

(d) Urban areas not encompassed by a MS4 service area were grouped into the "nonpoint source" category.

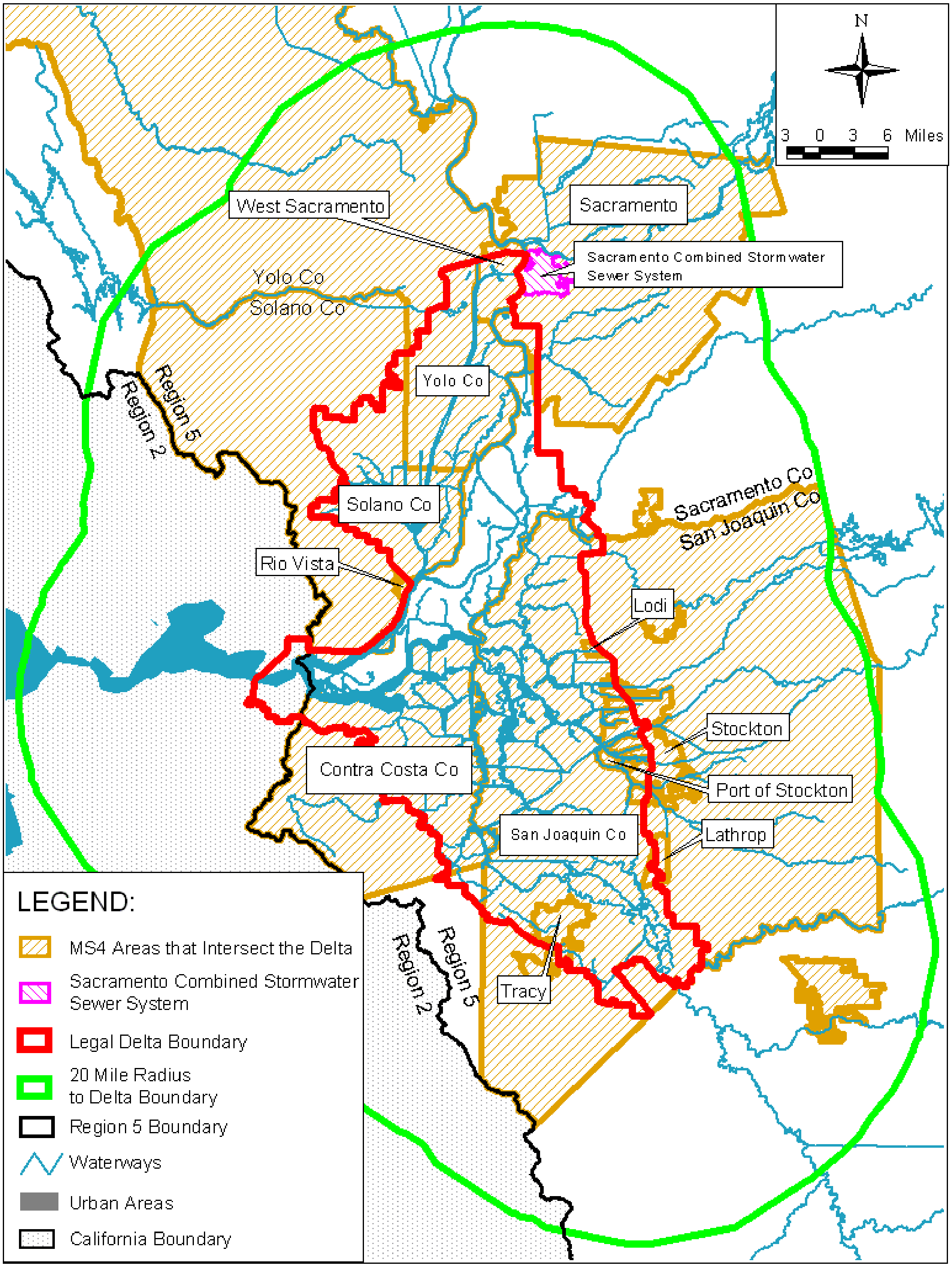

Figure 6.7: NPDES Permitted Municipal Separate Storm Sewer System (MS4) Areas in the Delta Region (Only those MS4 areas that intersect the statutory Delta boundary are labeled. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city or county boundaries.)

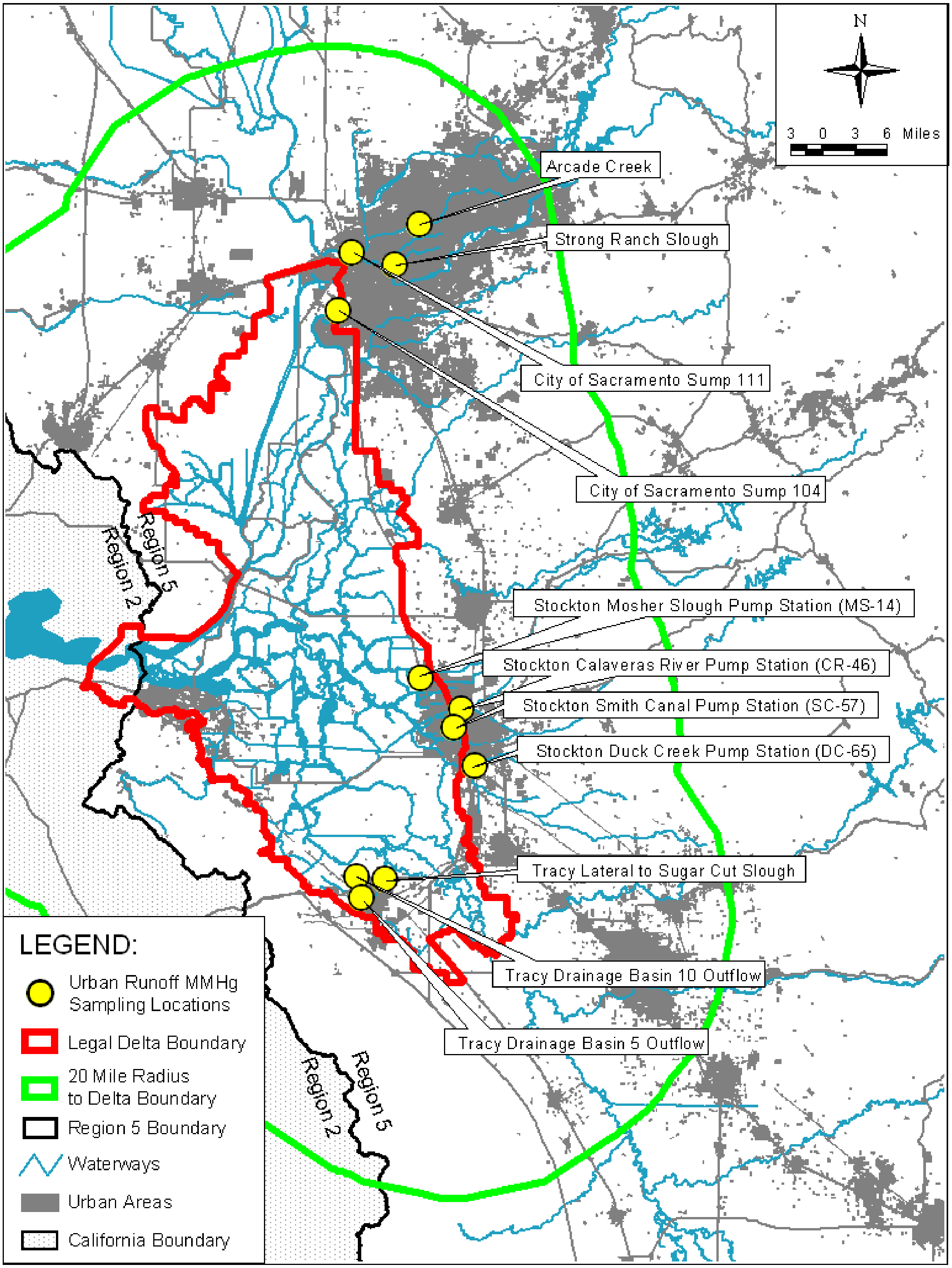

Figure 6.8: Urban Areas and Aqueous MeHg Sampling Locations in the Delta Region

Table 6.11: Summary of Urban Runoff Methylmercury Concentrations

Location	# of Samples	Minimum Conc. (ng/l)	Average Conc. (ng/l)	Maximum Conc. (ng/l)
DRY WEATHER				
Arcade Creek	9	0.099	0.358	1.213
Sacramento Strong Ranch Slough	2	0.158	1.099	2.040
Sacramento Sump 104	2	0.088	0.093	0.097
Sacramento Sump 111	2	0.135	0.176	0.217
Tracy Lateral to Sugar Cut Slough	1	0.091	0.091	0.091
Average of Location Averages:	**0.363 ng/l**			
WET WEATHER				
Arcade Creek	7	0.099	0.240	0.339
Sacramento Strong Ranch Slough	4	0.237	0.522	0.878
Sump 104	4	0.153	0.290	0.610
Sump 111	4	0.035	0.212	0.420
Stockton Calaveras River Pump Station	5	0.105	0.167	0.301
Stockton Duck Creek Pump Station	1	0.103	0.103	0.103
Stockton Mosher Slough Pump Station	4	0.084	0.125	0.189
Stockton Smith Canal Pump Station	4	0.099	0.263	0.533
Tracy Drainage Basin 10 Outflow	3	0.103	0.192	0.257
Tracy Drainage Basin 5 Outflow	3	0.110	0.138	0.191
Tracy Lateral to Sugar Cut Slough	3	0.040	0.400	0.918
Average of Location Averages:	**0.241 ng/l**			

Table 6.12: Average Annual Methylmercury Loading from Urban Areas within Each Delta Subarea for WY2000-2003

MS4 PERMITEE	DELTA SUBAREA							Grand Total
	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass	
City of Lathrop					0.27			0.27
City of Lodi	0.053							0.053
City of Rio Vista				0.014				0.014
City of Tracy					1.83			1.83
City of West Sacramento				0.62			1.09	1.71
County of Contra Costa	0.75		1.16			3.25		5.16
County of San Joaquin	0.57	0.051		0.19	2.62			3.43
County of Solano				0.074			0.085	0.16
County of Yolo				0.073			0.12	0.19
Port of Stockton MS4	0.39				0.010			0.40
Sacramento Area MS4				2.96				2.96
Stockton Area MS4	3.57				0.50			4.07
Urban Nonpoint Source	0.13	0.018		0.63	0.0022	0.024		0.81

Grand Total	5.47	0.068	1.16	4.56	5.22	3.28	1.30	21.1

Urban land use comprises a small portion of the surface area in the Delta and contributes only about 0.4% of the Delta methylmercury load (Table 6.2). In contrast, approximately 320,000 acres of urban land – about 42% of all urban area within the Delta source region – occur within 20 miles of the statutory Delta boundary, about one day water travel time upstream. In addition, some of the urban watersheds outside the Delta discharge via sumps into Delta waterways. These discharges were not included in the Delta load estimate. As a result, the urban contribution to the Delta methylmercury load may be underestimated.

To evaluate the potential contributions from upstream urban lands, the methylmercury loadings from the two MS4 service areas with the greatest urban acreage immediately outside the Delta were estimated. The sum of methylmercury loads from the Sacramento and Stockton MS4 areas may contribute more than 1% of methylmercury loading to the Delta (Table 6.13). These loads are expected to increase as urbanization continues around the Delta.

Table 6.13: Comparison of Sacramento & Stockton Area MS4 Methylmercury Loading to Delta Methylmercury Loading (a)

MS4 Service Area (Urban Acreage)	**Water Volume** (acre-feet) (b)	**MeHg Load** (grams/year)
Sacramento MS4 Urban Total	174,593	51
Stockton MS4 Urban Total	25,304	7.4
Total Delta Inputs (c)	19,425,472	4,933
Stockton & Sacramento Runoff as % of Total Delta Inputs	**1.0%**	**1.3%**

(a) The Sacramento and Stockton Area MS4s are the two MS4 service areas with the greatest urban acreage immediately outside the Delta, with urban land use areas 154,050 and 24,901acres, respectively.
(b) Refer to Section E.2.3 in Appendix E for urban runoff volume estimates for wet and dry weather, which were summed to estimate the annual average water volumes shown above.
(c) These values represent the sum of all tributary and within-Delta methylmercury sources shown in Table 6.2.

6.2.6 Atmospheric Deposition

Atmospheric deposition of methylmercury has not yet been measured within the Delta. However, several published papers provide reviews of methylmercury levels in wet deposition in a variety of locations around the world (e.g., Nguyen *et al.*, 2005; Lawson & Mason, 2001; Mason *et al.*, 1997 & 2000). These reviews indicate that the ratios of methyl to total mercury concentrations in wet deposition range from 0.25 to 6%, and that typically less than 1% of total mercury in wet deposition is methylmercury. As described in Section 7.1.4 and Table 7.1, total mercury loading from wet deposition to Delta water surfaces (direct deposition) was estimated to be 0.853 kg/yr (853 g/yr). A methyl to total mercury ratio of 1% was used to estimate the mass of methylmercury deposited by direct wet deposition:

Equation 6.2:

MeHg Mass = Total mercury mass * MeHg:TotHg
8.5 g/yr = 853 g/year * 0.01

Table 6.14 provides the methylmercury load estimates for direct deposition to waterways in each Delta subarea. Wet deposition to Delta waterways likely contributes less than 0.2% of all methylmercury entering the Delta (Table 6.2). Therefore, it is assumed that direct atmospheric input to Delta water surfaces is not a significant source of methylmercury. Methylmercury in wet deposition to land surfaces was not evaluated because it is incorporated in the estimates for loading from agricultural and urbanized lands described in Sections 6.2.4 and 6.2.5. Agricultural and urban areas comprise the majority of land surfaces in the Delta.

Table 6.14: Estimate of Direct Wet Deposition of Methylmercury to Delta Waterways

Delta Subarea	**Rainfall on Waterways** (acre-feet/yr) (a)	**WY2000-2003 Average Annual TotHg Load** (g/yr) (a)	**Estimated MeHg Load** (g/yr) (b)
Central Delta	35,127	321	3.2
Cosumnes / Mokelumne River	262	2.4	0.024
Marsh Creek	5	0.049	0.0005
Sacramento River	16,536	151	1.5
San Joaquin River	4,482	41	0.41
West Delta	25,102	229	2.3
Yolo Bypass-North	2,130	19	0.19
Yolo Bypass-South	9,853	90	0.90
TOTAL	**93,498**	**853**	**8.5**

(a) Total mercury loading from precipitation on surface water in the Delta (direct deposition) was estimated by multiplying the average mercury concentration in North Bay/Martinez rainwater (Section 7.1.4, Table 7.10) by the average rainfall volume to fall on Delta water surfaces during WY2000-2003 (Section E.2.3 in Appendix E).

(b) The published literature indicates that ratios of methyl to total mercury concentrations in wet deposition typically range from 0.25% to 6%, and that typically less than 1% of total mercury in wet deposition is methylmercury. A methyl to total mercury ratio of 1% was used to estimate the mass of methylmercury deposited to waterways in each subarea.

6.3 Methylmercury Losses

The following were identified as contributing to methylmercury losses from the Delta: water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, biotic uptake and unknown loss term(s). Table 6.15 lists the average methylmercury concentrations and estimated average annual loads associated with the losses for the WY2000-2003 period, a relatively dry period that encompasses the available concentration data for the major Delta inputs and exports. Figure 6.9 shows the aqueous monitoring locations for major methylmercury exports and the approximate locations of recent dredging projects.

Table 6.15: Methylmercury Concentrations and Loads Lost from the Delta for WY2000-2003.

	Average Annual Load (g/yr)	**% All MeHg**	**Average Aqueous Concentration** (ng/l)
Outflow to San Francisco Bay (X2)	1,717	70%	0.08
Dredging	341	13.8%	- - -
State Water Project	203	8.2%	0.05
Delta Mendota Canal	201	8.2%	0.06
Photodegradation	*To Be Determined*		
Accumulation in Biota	*Unknown*		
TOTAL EXPORTS:	**2,462 g/yr (2.5 kg/yr)**		

6.3.1 Outflow to San Francisco Bay

Outflow to San Francisco Bay is the primary way that methylmercury is lost from the Delta. Methylmercury in Delta outflow to San Francisco was evaluated by collecting samples at X2. X2 is the location in the Bay-Delta Estuary with 2 o/oo bottom salinity. The location of X2 moves as a function of both tidal cycle and freshwater inflow, typically between the Cities of Martinez and Pittsburg, west of the legal Delta boundary. This salinity was chosen because 2 to 3 o/oo salinity is the normal osmotic tolerance of freshwater organisms, and a goal of the CALFED studies was to estimate the methylmercury exposure of these organisms.

Staff from the Central Valley and San Francisco Bay Central Valley Water Boards has agreed to consider Mallard Island as the boundary between the two regions for control of mercury. The site was selected as it is near the legal boundary and has a U.S. Geological Survey flow gauge. Central Valley Water Board staff has begun collecting methylmercury concentration data at Mallard Island and will use this to better estimate advective and dispersive flux of methylmercury from the Central Valley to San Francisco Bay. The data will be collated and a report prepared in the fall of 2006.

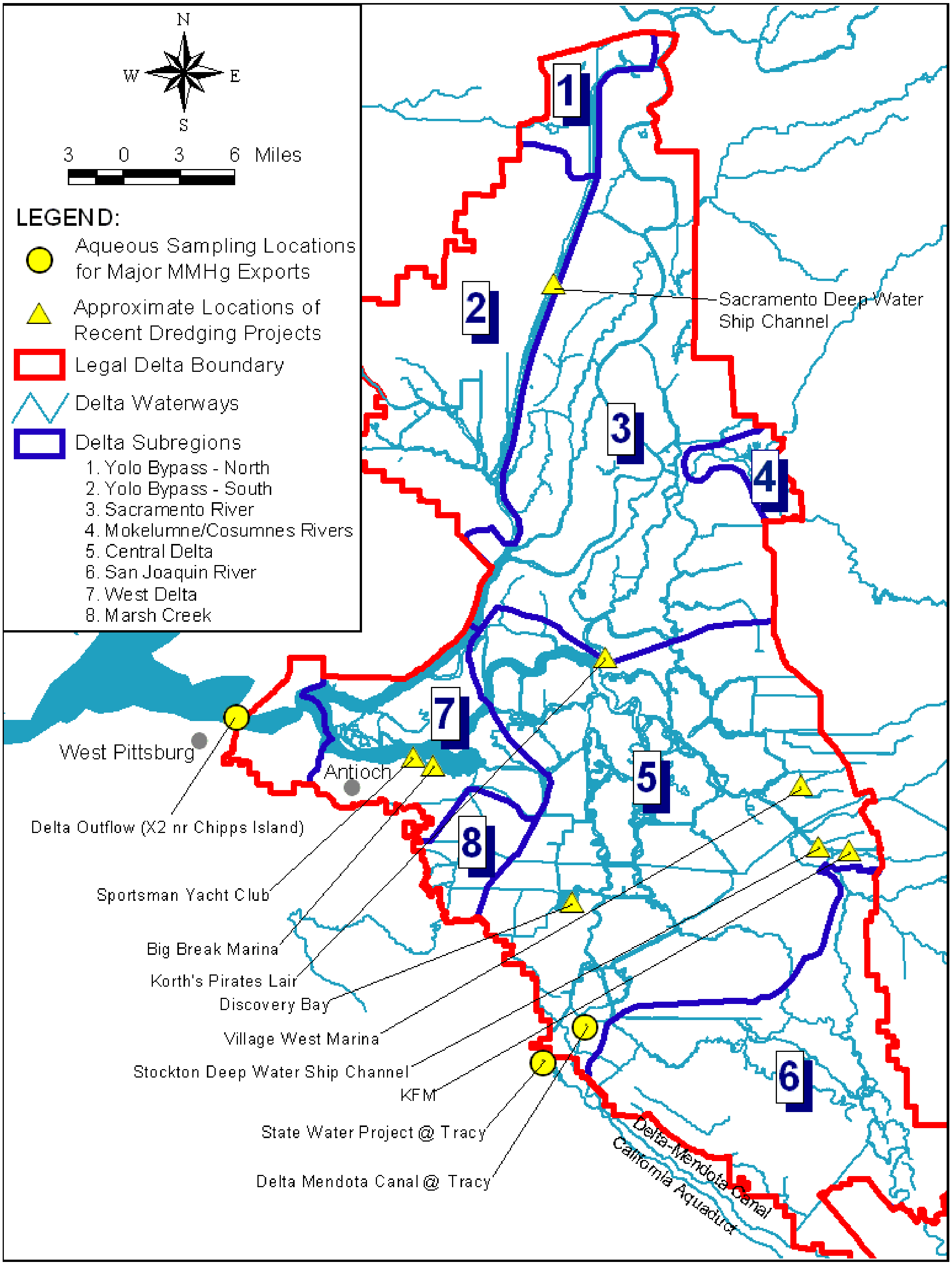

Figure 6.9: Aqueous Monitoring Locations for Major MeHg Exports and Approximate Locations of Recent Dredging Projects.

Central Valley Water Board staff conducted monthly aqueous methylmercury sampling at X2 from March 2000 to September 2001 (Foe, 2003) and from April to September 2003. Figure 6.10 and Table 6.16 summarize the export data. Methylmercury concentrations at X2 averaged 0.075 ng/l and ranged from below detection limits to 0.241 ng/l. Net daily Delta outflow water volumes were obtained from the Dayflow model (Section E.2.4 in Appendix E). Methylmercury concentrations for X2 and net daily Delta outflows were regressed against each other to determine whether flow could be used to predict methylmercury concentration (Appendix F). The regression was significant at $P<0.05$ and accounted for about 20% of the variation in methylmercury concentrations. The regression-based export loads was 2,086 g/yr (Appendix F).

An alternate approach is to use average monthly methylmercury concentrations to estimate Delta exports. Concentration data were pooled by month to calculate monthly average concentrations for WY2000-2003 (Tables D.1 and D.2 in Appendix D). Monthly average concentrations were multiplied by monthly average flows for WY2000-2003 to estimate monthly loads and summed to calculate an annual average methylmercury load for WY2000-2003 of 1,717 g/yr. The latter estimate appears similar to the regression-based estimate (2,086 g/yr). Table 6.15 uses an advective export rate of 1,717 g/yr to San Francisco Bay. This accounts for approximately 70% of Delta methylmercury losses. No attempt was made to estimate dispersive loads. It is not known whether dispersive or tidal flows would increase or decrease the net methylmercury load exported to the Bay area.

6.3.2 South of Delta Exports

Water diversions to southern California account for approximately 16% of Delta methylmercury losses (Table 6.15). Methylmercury in Delta Mendota Canal (DMC) and State Water Project (SWP) exports to southern California were evaluated by collecting water samples from the DMC canal off Byron Highway (County Road J4) and from the input canal to Bethany Reservoir, respectively. Bethany is the first lift station on the State Water Project canal system and is about one mile south of Clifton Court Forebay in the Delta. Figure 6.9 illustrates the sampling locations.

Central Valley Water Board staff conducted monthly methylmercury sampling at the DMC and SWP from March 2000 to September 2001 (Foe, 2003) and from April 2003 to April 2004. Figure 6.10 and Table 6.16 summarize methylmercury concentrations. The volume of water exported by the DMC and SWP was obtained from the Dayflow model (Section E.2.4 in Appendix E). Like at X2, methylmercury concentrations were regressed against daily flow to determine whether the concentrations could be predicted from the flow (Appendix F). Neither regression was significant ($P<0.05$). Therefore, average methylmercury concentrations were used to estimate SWP and DMC export loads of 203 and 201 g/yr (Table 6.15). Additional methylmercury data is being collected at both pumping sites to better characterize methylmercury loads. This data should be available in an interpretive report in the winter of 2006.

6.3.3 Export via Dredging

Sediment is dredged at various locations in the Delta to maintain ship channels and marinas. No data have been gathered on methylmercury levels in dredge material removed from the Delta. To determine whether dredging activities could result in notable methylmercury loss from the Delta, a preliminary load

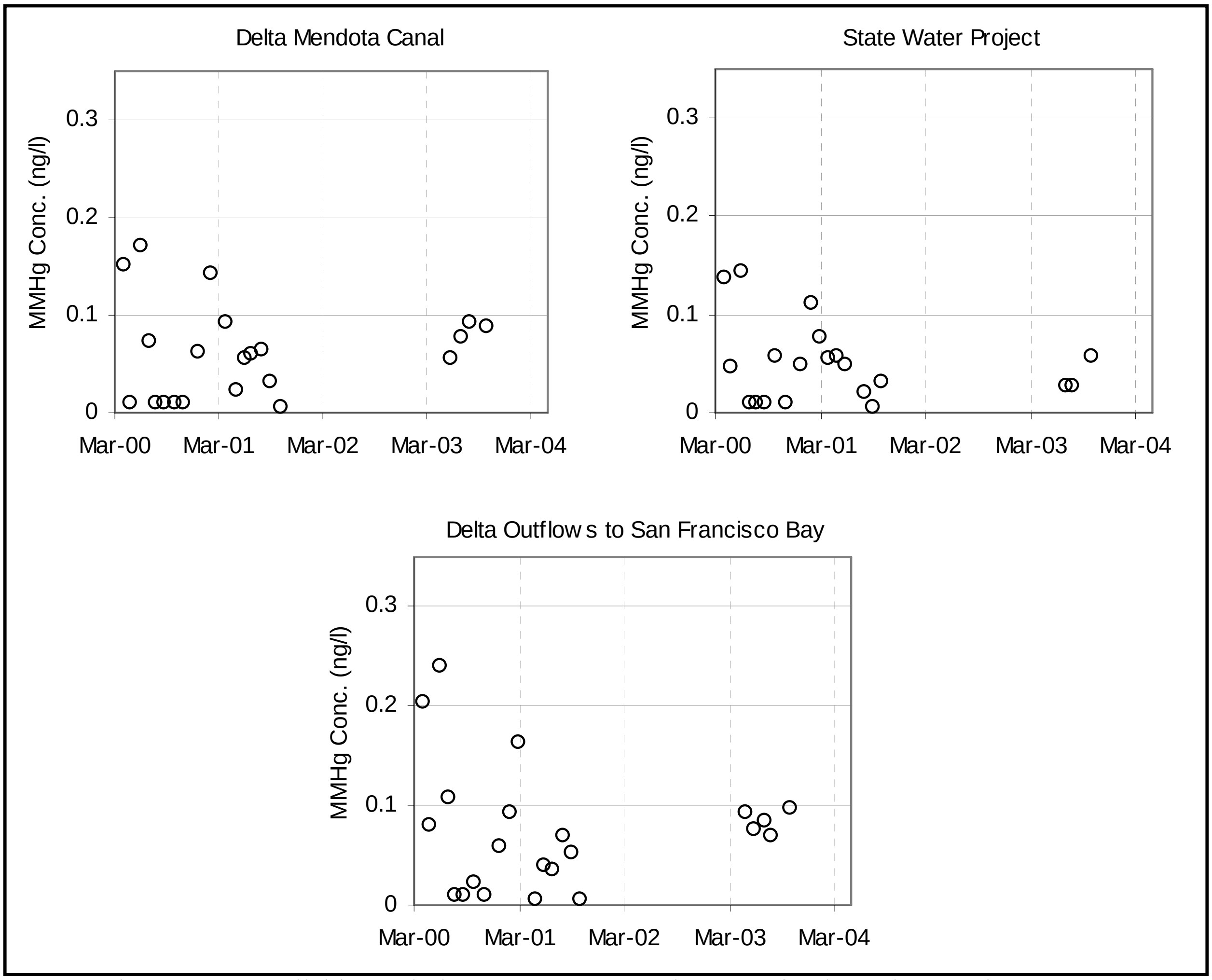

Figure 6.10: Available Methylmercury Concentration Data for the Delta's Major Exports

Table 6.16: Methylmercury Concentrations for the Delta's Major Exports

Site	# of Samples	Min. MeHg Conc. (ng/l) (a)	Ave. MeHg Conc. (ng/l)	Annual Ave. Conc. (ng/l) (b)	Median MeHg Conc. (ng/l)	Max. MeHg Conc. (ng/l)
Delta Mendota Canal	21	ND	0.062	0.064	0.061	0.171
State Water Project	20	ND	0.064	0.054	0.050	0.291
Outflow to San Francisco Bay (X2)	22	ND	0.075	0.083	0.070	0.241

(a) ND: below method detection limit.
(b) Sampling of these exports took place between March 2000 and September 2003. Methylmercury concentration data were pooled by month to estimate monthly average methylmercury concentrations and loads (Tables D.1 and D.2); the monthly average loads were summed to estimate annual average methylmercury loads for water years 2000-2003. The monthly average concentrations were averaged to estimate annual average concentrations, which were included in Table 6.15.

estimate was developed using available dredge volume and total mercury information and surficial sediment methylmercury concentration data. Methylmercury removed by dredge activities could account for almost 14% of the identified methylmercury exports from the Delta (Table 6.15).

Dredge material is typically pumped to either disposal ponds on Delta islands or upland areas with monitored return flow. Table 6.18 provides details on recent dredge projects within the Delta and Figure 6.9 shows their approximate locations. The Sacramento and Stockton deep water channels have annual dredging programs; the locations dredged each year vary. Dredging occurs at other Delta locations when needed, when funds are available, or when special projects take place. Approximately 533,400 cubic yards of sediment are dredged annually on average, with 199,000 cubic yards from the Sacramento Deep Water Ship Channel and 270,000 cubic yards from the Stockton Deep Water Channel. Other minor dredging projects at marinas remove sediment at various frequencies for a combined total of about 64,400 cubic yards per year. Average mercury concentrations in the sediment for the project sites range from 0.04 to 0.44 mg/kg (dry weight). The annual mass of mercury removed from the Delta through dredging projects is approximately 57 kg/year. Section 7.2.3 provides a description of the methods used to estimate the annual mass of total mercury removed by dredging and the uncertainty in the estimate. None of the dredging projects analyzed sediment samples for methylmercury. Heim and others (2003) evaluated surficial sediment MeHg:TotHg at several locations in the Sacramento and Stockton Deep Water Channels (Table 6.17), where nearly 90% of all dredged materials from the Delta are removed. The average MeHg:TotHg of 0.006 was used to estimate the mass of methylmercury removed by dredging projects:

Equation 6.3:

$$\text{MeHg Mass} = \text{Total mercury mass} * \text{MeHg:TotHg}$$
$$341 \text{ g/yr} = 57 \text{ kg/year} * 1000 \text{ (g/kg)} * 0.006$$

Use of surficial sediment MeHg:TotHg to estimate methylmercury mass removed by dredging assumes that MeHg:TotHg is consistent throughout all depths of sediment in the dredged areas, which may overestimate the mass removed if MeHg levels actually decrease with depth. In addition, methylmercury production may increase after dredging activities if the newly exposed sediment has higher total mercury concentrations. Central Valley Water Board staff recommends that dredgers quantify the amount of methylmercury removed and that the mercury concentration of fine grain material in newly exposed sediment be assayed (see Chapter 4 in the Proposed Basin Plan Amendment draft staff report).

Table 6.17: MeHg:TotHg in Deep Water Ship Channel Surficial Sediments

	MeHg Conc. (ng/g)	**TotHg Conc.** (ng/g)	**MeHg:TotHg Ratio**
Sacramento Deep Water Ship Channel			
Sacramento River DWSC	0.49	194.70	0.0025
Stockton Deep Water Channel			
Little Connection Slough	0.20	82.51	0.0024
Headreach Cutoff	1.86	89.46	0.0208
Port of Stockton Turnabout #1	0.32	193.78	0.0017
Port of Stockton Turnabout #2	0.32	130.30	0.0025
		AVERAGE RATIO:	**0.006**

(a) Source: Heim *et al.*, 2003. Latitude/longitude coordinates provided with the above samples indicated that these were collected within the dredged deep water ship channels.

Table 6.18: Recent Dredge Projects within the Delta.

Delta Dredging Project	Project Location	Volume of Dredge Material (cubic yards)	Dredge Frequency	Disposal Location (upland, Delta island, wetland areas, etc.)	Mean Sediment Mercury Conc. (mg/kg, dry wt) (a)	# of Samples	Standard Dev.	t Value (p=0.975, conf 95%, df =n-1)	Total Weight of Mercury Removed (kg)	Annual Weight of Mercury Removed (a) (kg)	Annual Weight of Sediment Removed (Mkg, dry wt)	Annual Volume of Water Removed (acre-feet)	Does Effluent Return to a Receiving Water?	Average Effluent Hg Conc. (μg/l)
Sac. River Deep Water Ship Channel (b)	Sacramento River	199,000	Annually	Delta Island/ upland	0.37 ±3.93	2	0.4377	12.71	42	42 ±446 (n)	110.5	89.6	No	0.05 to 0.1
Stockton Deep Water Channel (c)	San Joaquin River	270,000	Annually	Delta Islands	0.083 ±0.023	28	0.0594	2.052	13	13 ±3.5	150.0	121.5	No	0.05 to 0.13
Village West Marina (d)	14-Mile Slough	70,000	Every 10 years	Delta Islands	0.043 ±0.014	3	0.0058	4.303	1.7	0.2 ±0.057	3.9	3.2	Yes (l)	0.05
KFM (e)	San Joaquin River	3,000	One time	Upland	*Unknown*						1.7	1.4	No	0.05
Korths Pirates Lair (f)	Mokelumne River	15,000	Every 5 years	Upland	0.15 ±0.11	2	0.0120	12.71	1.3	0.25 ±0.18	1.7	1.4	No	0.05
Big Break Marina (g)	San Joaquin River	12,000	Every 5 years	Upland	0.41 ±0.24	6	0.2318	2.571	2.8	0.55 ±0.33	1.3	1.1	No	0.25
Sportsman Yacht Club (h)	San Joaquin River	10,000	Every 5 years	Upland	0.12 ±0.014	3	0.0058	4.303	0.70	0.14 ±0.016	1.1	0.9	No	0.05
Discovery Bay (i)	Delta	50,000 (j)	Annually	Upland	0.027 ±0.018	7	0.0195	2.447	0.78	0.78 ±0.51	27.8	22.5	Yes (k, l)	0.05
Annual Averages (m)		**533,400 cubic yards**								**57 ±451 kg** (n)	**349 Mkg**	**283 a-ft**		

(a) The uncertainty of the mercury load values was estimated by calculating the 95% confidence interval for the mean of the concentration data for each project.
(b) U.S. Army Corps of Engineers, 2002 NOI (Notice of Intent) Sacramento DWSC.
(c) U.S. Army Corps of Engineers, 2000-2003 NOI Stockton DWSC.
(d) DCC Engineering Co, Inc., Village West Dredge Material Test, September 5, 2000.
(e) KFM, 401 Water Quality Certification.
(f) Anderson Engineers, 2003 Sediment Sampling and Analysis Plan for Korths Pirates Lair.
(g) Subsurface Consultants, Inc., Environmental Site Assessment 2001 & Aquifer Sciences, Inc., Pre-Dredge Sampling and Analysis Plan July 29, 2003.
(h) Padre Associates, Inc., Laboratory Analytical Results of Proposed Dredge Material and Associated Waste Classification May 23, 2003.
(i) Kennetic Laboratories/ToxScan, Inc., Sediment Properties and Chemistry April 2002, Discovery Bay, 2003 Final Water Quality Monitoring Report, WDR Order No. R5-2003-0027.
(j) Discovery Bay assumptions: The initial dredge project was 153,000 cubic yards, and 50,000 cubic yards/year thereafter. Therefore, assume 50,000 cy/year.
(k) WDR Order N. R5-2003-0027 indicates effluent returned to Discovery Bay averaged 3 mgd for several days to several weeks; staff assumed discharge period is 14 days/year.
(l) Two dredging projects, Village West Marina and Discovery Bay, had effluent that returned to Delta waters. The volume of effluent returned to receiving waters by the Discovery Bay project was approximately 42 million gal/year. The volume of effluent returned by the Village West Marina project is unknown. Staff estimated that the annual weight of mercury returned by the Discovery Bay dredge effluent was 0.008 kg, assuming that all water was returned.
(m) Annual averages do not include KFM, a one-time project.
(n) The uncertainty associated with the amount of mercury removed by dredging in the Sacramento Deep Water Ship Channel is particularly substantial (±446 kg), as a consequence of its calculation being based on only two sample results (0.68 and 0.061 mg/kg mercury) that have a tenfold range.

6.3.4 Other Potential Loss Pathways

Accumulation by biota and photodegradation throughout the Delta has not yet been evaluated. The amount of methylmercury accumulating in aquatic biota is not known. However, studies could be undertaken to ascertain the rate of transfer from the abiotic to the biotic component of the food web. Preliminary study results for the Sacramento River near Rio Vista indicate relative surface water photodegradation rates of about 30% of the dissolved methylmercury per day at the top half meter of water (Byington *et al.*, 2005). Byington and others' preliminary results are similar to photodegradation rates observed in Florida and Canada. Methylmercury photodegradation rates in a boreal forest lake in northwestern Ontario, Canada, ranged between -3 and 27% per day, with the highest rates at the lake surface (Sellers & Kelly, 2001). In the Everglades, Krabbenhoft and others (1999) observed methylmercury degradation rates ranging from 2 to 15% per day. Krabbenhoft and others (1999 & 2002) also found that the majority of photodegradation occurred in the top half meter of water; however, they also found that the rate of degradation was largely dependent on the concentration of dissolved organic carbon. The large surface to depth ratio of the Delta, coupled with its relatively long residence time, may result in significant loss of methylmercury by photodegradation. Byington and others' extrapolation of their preliminary study results suggests a loss of about 4 g/day over the entire Delta. Photodemethylation experiments are continuing as part of an ongoing CALFED-funded project (Proposal ERP-02-C06-B).

6.4 Delta Methylmercury Mass Budget & East-West Concentration Gradient

Figure 6.11 provides an idealized illustration of the Delta's average daily methylmercury imports and exports based on the annual loads presented in Tables 6.2 and 6.15. *In situ* sediment production and tributary water bodies account for about 30 and 60%, respectively, of methylmercury inputs to the Delta. Agricultural return flow and NPDES-permitted wastewater treatment plants are responsible for about 7% of the load while urban runoff contributes about half a percent.

The difference between the sum of known inputs and exports is a measure of the uncertainty of the loading estimates and of the importance of other unknown processes at work in the Delta. As noted in Section 6.2, the sum of WY2000-2003 water imports and exports balances within approximately 2%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget does not balance. Average annual methylmercury inputs and exports were approximately 13.5 g/day (4.9 kg/yr) and 6.7 g/day (2.5 kg/yr), respectively (Tables 6.2 and 6.15 and Figure 6.11). Exports are only about 50% of inputs, suggesting that the Delta acts as a net sink for methylmercury.

A special study was conducted in the summer of 2001 to ascertain the location where much of the decrease in methylmercury occurred (Foe, 2003). Three transects were run down the Sacramento River and out toward San Francisco Bay, the water path from the main tributary source (Sacramento River) to the main export of methylmercury (Suisun Bay). The largest decrease in concentration consistently occurred in the vicinity or immediately downstream of Rio Vista (Figure 6.12). The drop in concentration was between 30 and 60%. The processes contributing to the loss are not known but are the subject of ongoing CALFED research (ERP-02-C06-B, Tasks 5A and 5B). For example, as described in the previous section, preliminary photodegradation study results for the Sacramento River near Rio Vista indicate relative surface water photodegradation rates of about 30% of the dissolved methylmercury per day at the top half meter of water (Byington *et al.*, 2005). Byington and others' extrapolation of their preliminary study results over all Delta waters suggests a loss of about 4 g/day, nearly 60% of the 6.7 g/day unknown loss rate illustrated in Figure 4.11. Additional research is ongoing or proposed in Chapter 4 of the draft BPA report (Implementation) that includes monitoring to better characterize source concentrations and loads. Improvements made to the load estimates could affect the methylmercury load allocations calculated in Chapter 8.

Key points for the methylmercury source analysis are listed after Figures 6.11 and 6.12.

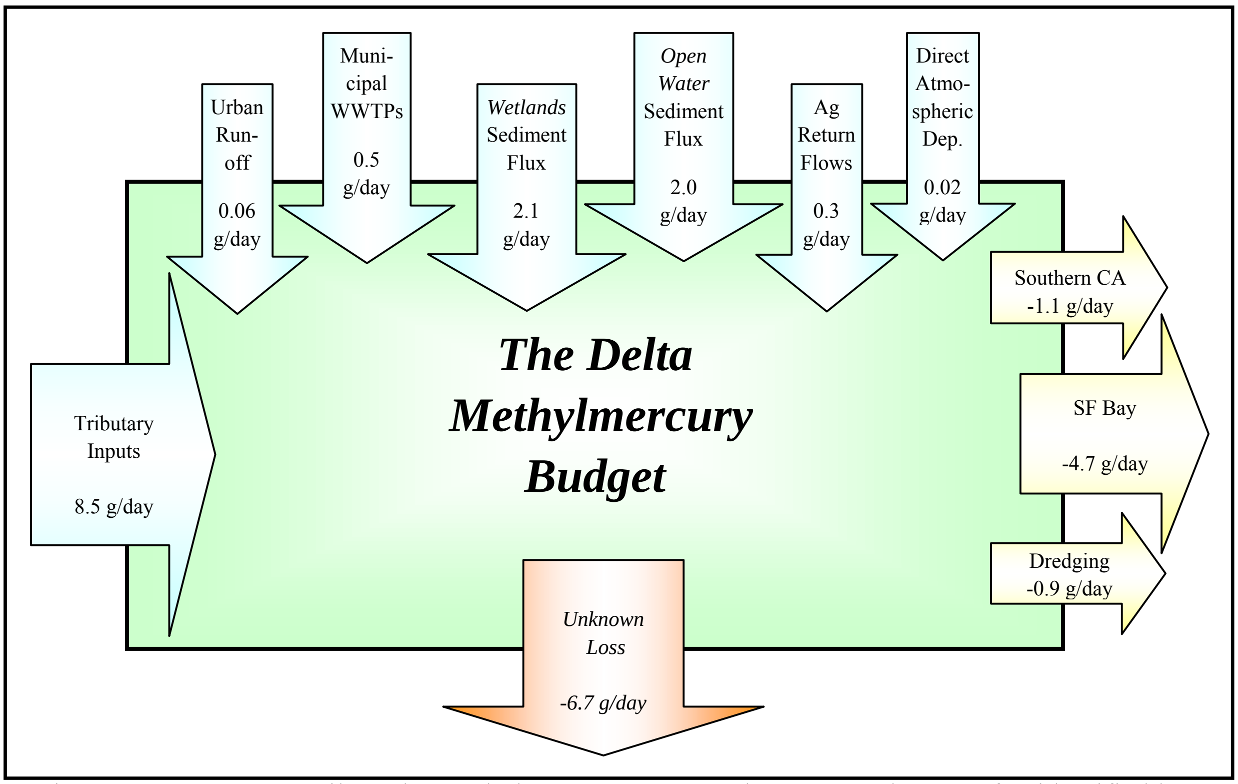

Figure 6.11: Average Daily Delta Methylmercury Inputs and Exports. The rate of unidentified loss processes was determined by subtracting the sum of the inputs from the sum of the exports.

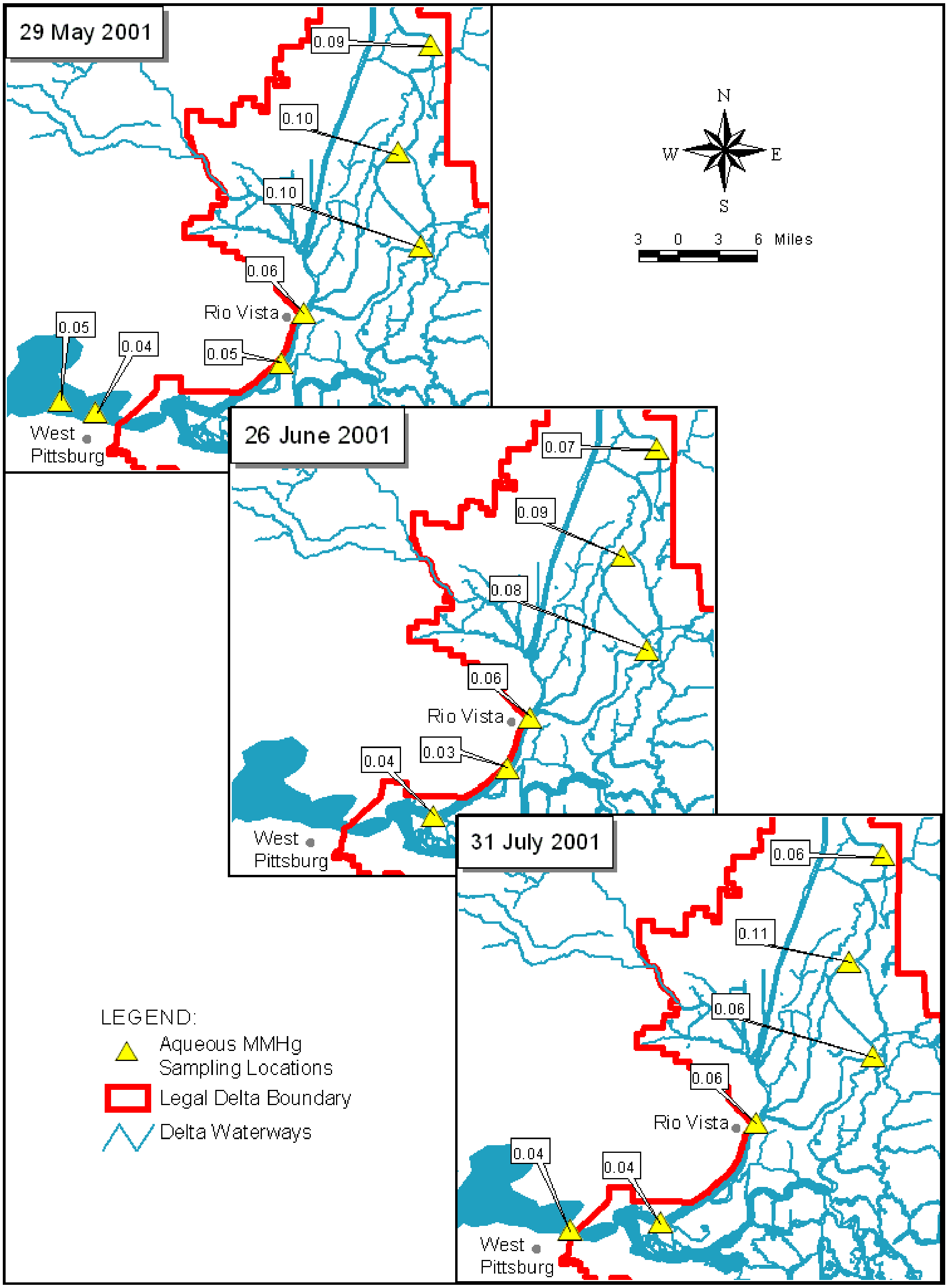

Figure 6.12: Water Sampling Transects down the Sacramento River to Ascertain Location of Methylmercury Concentration Decrease. Westernmost sampling stations changed with each transect depending on the locations of 1 o/oo through 5 o/oo bottom salinities, which move as a function of tidal cycle and freshwater inflow. Data source: Foe, 2003.

Key Points

- Sources of methylmercury in Delta waters include tributary inflows from upstream watersheds and within-Delta sources such as sediment flux, municipal and industrial wastewater, agricultural drainage, and urban runoff. Approximately 63% of identified methylmercury loading to the Delta comes from tributary inputs while within-Delta sources account for approximately 37% of the load.
- Losses include water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, uptake by biota and unknown loss term(s). Outflow to San Francisco Bay accounted for more than 70% of identified methylmercury exports.
- The sum of WY2000-2003 water imports and exports balances within approximately 2%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget does not balance. A comparison of the sum of identified inputs (4.9 kg/yr) and exports (2.5 kg/yr) indicates that there is an unknown loss term of approximately 50%. Preliminary study results suggest that photodegradation may explain about 60% of the loss.